Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

Workflow for Virtual Geomatics (VG4D)

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Report Number:

AHMCT Research Report: UCD-ARR-11-11-30-01

Interim Report of Contract: 65A0368

November 30, 2011

California Department of Transportation

Division of Research and Innovation

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Workflow for Virtual Geomatics (VG4D)	November 30, 2011
	6. Performing Organization Code
7. Author(s):	8. Performing Organization Report No.
Vaibhav Soni, Kin Yen, Ty Lasky, & Bahram Ravani	UCD-ARR-11-11-30-01
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
AHMCT Research Center Dept of Mechanical & Aerospace Engineering Davis, California 95616-5294Davis, California 95616-5294	11. Contract or Grant IA 65A0368
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
California Department of Transportation	Interim Report
Division of Research and Innovation, MS-83 1227 O Street, Sacramento CA 95814	14. Sponsoring Agency Code Caltrans
15. Supplementary Notes	

16. Abstract

This report presents the Caltrans Workflow for Virtual Geomatics (VG4D). Virtual Geomatics is a powerful and efficient point cloud processing engine designed to handle large datasets (billions of points). The application's complete end-to-end workflow includes automatic classification, smart feature extraction, automatic digitization, batch processing, asset management, project management/tracking, and report /deliverable generation. This report includes step-by-step workflow for Virtual Geomatics using Caltrans data and examples.

17. Key Words	18. Distribution Statement
Mobile laser scanning, LiDAR, MTLS, point cloud, 4D, Virtual Design and Construction, feature extraction, deliverables, project management, LAS files	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

20. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	77	

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(PF V2 1, 6/30/92)

Abstract

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

Disclaimer/Disclosure

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California – Davis, and the Division of Research and Innovation at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, State and Federal governments and universities.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, or the University of California. This report does not constitute a standard, specification, or regulation.

List of Acronyms and Abbreviations

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology
CAD	Computer Aided Design
Caltrans	California State Department of Transportation
DRI	Division of Research and Innovation
GB	Gigabyte
MB	Megabyte
OS	Operating System
RAM	Random Access Memory
UCD	University of California-Davis
USB	Universal Serial Bus
LiDAR	Light Detection And Ranging
XML	eXtensible Markup Language
LAS	Log ASCII Standard
TIN	Triangulated Irregular Network
GIS	Geographic Information Systems
ASCII	American Standard Code for Information Interchange
TIFF	Tagged Image File Format
KML	Keyhole Markup Language
ESRI	Environmental Systems Research Institute
VG4D	Virtual Geomatics 4D

Chapter 1: Introduction

VG4D Smart LiDAR Analyzer Pro, the flagship product of the SmartLiDAR™ solutions, is one of the most comprehensive and flexible solution available today. The robust features include customized application-oriented workflow for airborne, mobile, corridor and static LiDAR/point cloud datasets. Built to fully exploit LiDAR point cloud data to its fullest, the standards-based solution features a powerful and efficient point cloud processing engine designed to handle large datasets (billions of points). The application's complete end-to-end workflow includes automatic classification, smart feature extraction, automatic digitization, batch processing, asset management, project management/tracking, report /deliverable generation and much more.

VG4D is one of several programs we have evaluated. Others include InnovMETRIC's PolyWorks, Leica's Cyclone, Trimble's Realworks Survey, and MicroSurvey's PointCloud CAD. These will be documented based on available resources.

Highlights of VG4D include:

- End-to-end LiDAR processing in a stand-alone solution; requiring no additional 3rd party software
- Efficient "point cloud" LiDAR Engine capable of handling very large datasets
- Powerful and user-friendly 3D visualization with many "easy-to-use, one-click" capabilities
- Versatile data export capabilities coupled with real-time tracking and reporting
- Comprehensive deliverables for all industry-recognized engineering applications
- Integrates seamlessly with other VG4D SmartLiDAR applications to lower cost of ownership

Let's have a quick look at how the workflow for the software looks like and it would be discussed in details in subsequent chapters in the report.

OVERVIEW OF WORKFLOW

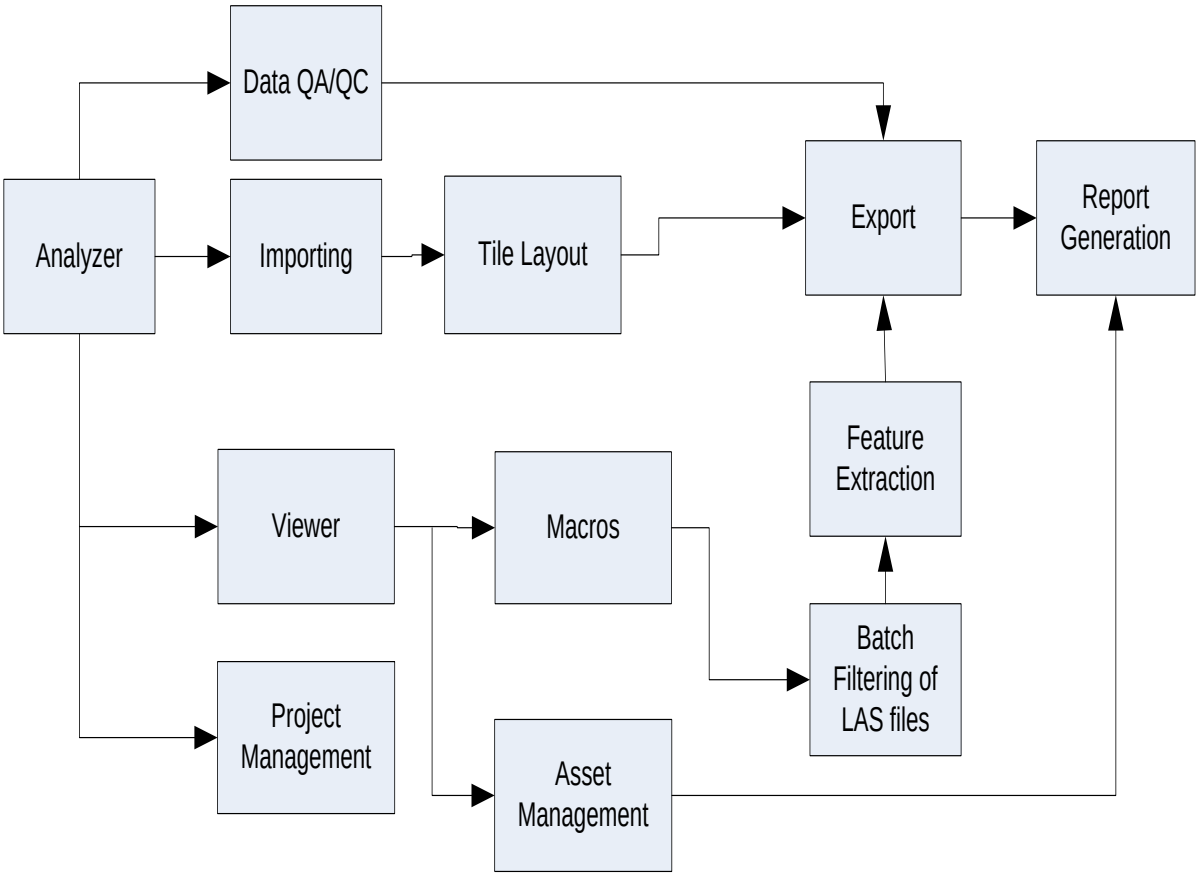


Figure 1: Workflow for VG4D

The software has two modules: Analyzer and Viewer. One may directly open the files in Viewer but the files would not be saved. Also some important functions like Feature Extractions cannot be executed if the file is not opened via the Analyzer.

File System of VG4D: VG4D recognizes two main types of files:

- LAS File: A public file format for the interchange of LIDAR data between vendors and customers. For more information, please refer: http://www.asprs.org/a/society/committees/lidar/lidar_format.html
- Shape file: This file format describes geometries: points, polylines and polygons. Each item could also have attributes that describes the items, such as name. For more information please refer: http://en.wikipedia.org/wiki/Shapefile#Shapefile_shape_format_.28.shp.29

LiDAR Analyzer

The LiDAR Analyzer is the interface where the VGP Projects are created and maintained. In this window we have a standard toolbar and LiDAR Analyzer Toolbar.

The user will be able to view only in 2 dimensions (in X, Y); shape files of all the LAS files imported are created to give the user an overview of the project bounds. The LiDAR Analyzer has many tools for performing batch processes, generating reports, performing manual checks and feature extraction, extracting LAS file information, invoking the 3D viewer, creating deliverables and many more. Each of these tools will be discussed in detail and the steps to use them.

STARTING VG4D:

- Click on the LiDAR Analyzer Pro Icon. A window opens as shown below:

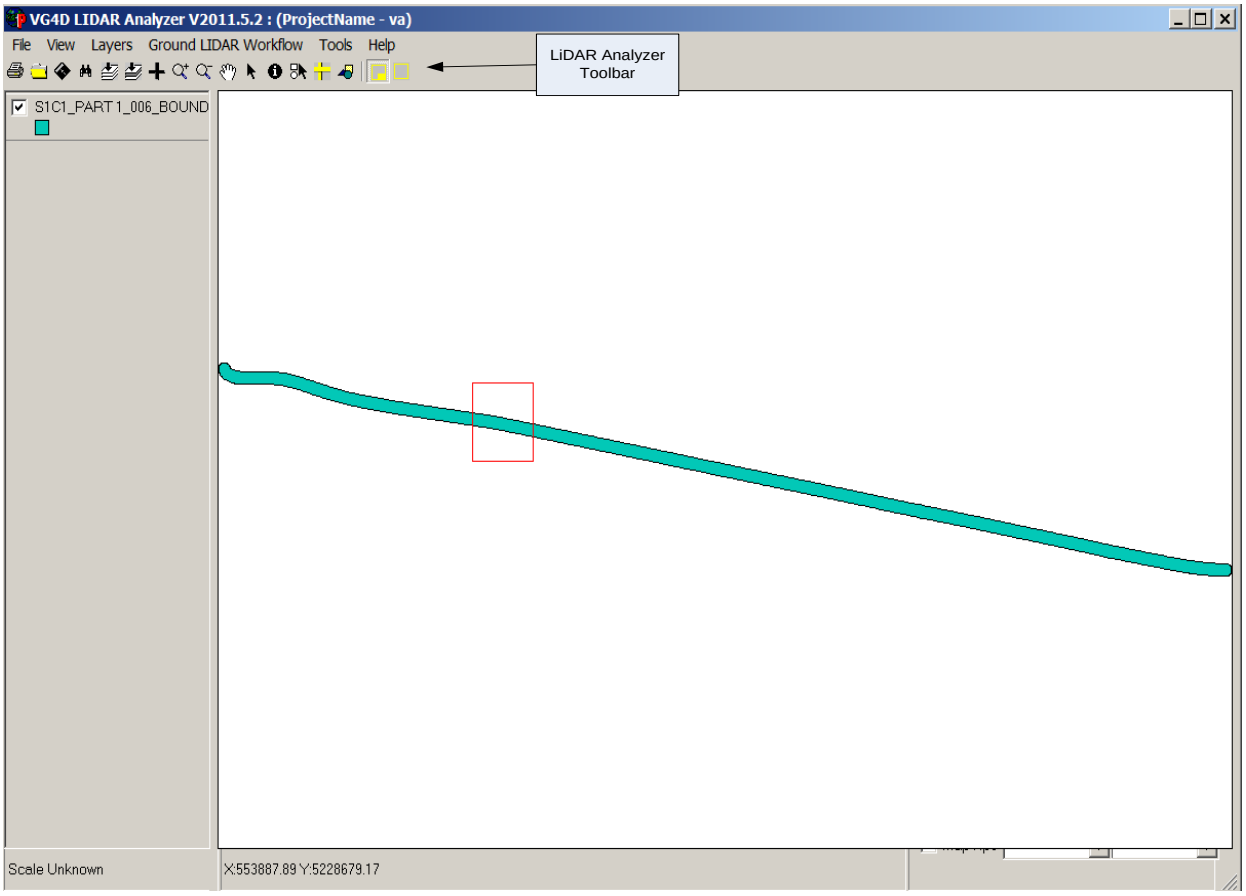


Figure 2: Window of LiDAR Analyzer

The Workflow has 4 main parts:

- Data QA/QC
- Importing

- LiDAR Viewer
- Project Management

Each of these workflows has several sub-processes which would be described in this report.

Let's have a quick look at the Analyzer and its toolbar.

- To start LiDAR Analyzer left-click on LiDAR Analyzer Pro Icon on your desktop.

LiDAR Analyzer Toolbar

Figure 3: Toolbar of LiDAR Analyzer

 - Open View: - For opening a saved view of the project

 - Save View – Saves current view settings so they can be opened again. The software will automatically prompt the user to save the view when the software is shut down

 - Find

 - Full Extent – Zooms view out ot the full project's extent

 - Layer Extent – Zooms view to the full extent of the selected layer

 - Add New Layer – Add additional shape files or image files to the project background

 - Zoom in – Click and drag a rectangle to zoom into, or click and zoom into the location of the mouse

 - Zoom out - Click and zoom out from the location of the mouse

 - Pan – Click and drag mouse to pan map view

 - Pointer

 - Identity – Click on a tile boundary, flight line boundary or any other polygon and view specific information

 - Spatial Select – Click and drag to select multiple objects or click individual objects to select

 - Distance Measuring Tool/Ruler

 - Graphics Tool – For drawing polygons

 - Invoke VG4D – Viewer by Rectangle – Click and drag to draw a rectangle of area of interet to be viewed in the 3D viewer. No editing or filtering functions will be available

 - Invoke VG4D – Viewer by Tile – Select a tile to view point cloud in the 3D viewer. The tile will be opened in the 3D Viewer with filtering and editing functions

Chapter 2: Importing Files and Project Management

Starting a Project

- Click on Open Project

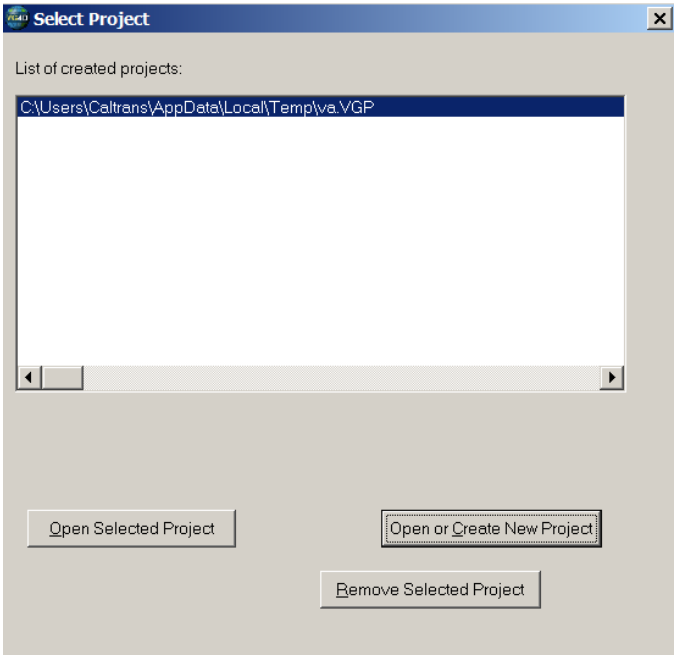


Figure 4: Select Project Window

- A pop up window opens showing list of existing projects in the default folder.
- A new project can be create using Open or Create New Project
- A project would have an extension .VGP

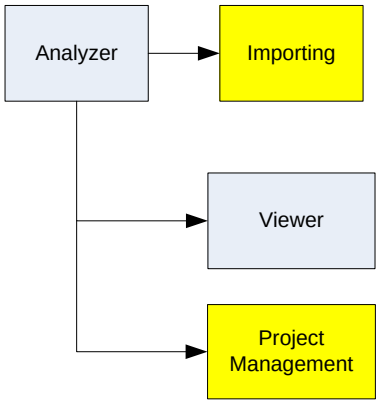


Figure 5: Workflow Progress

Project Settings

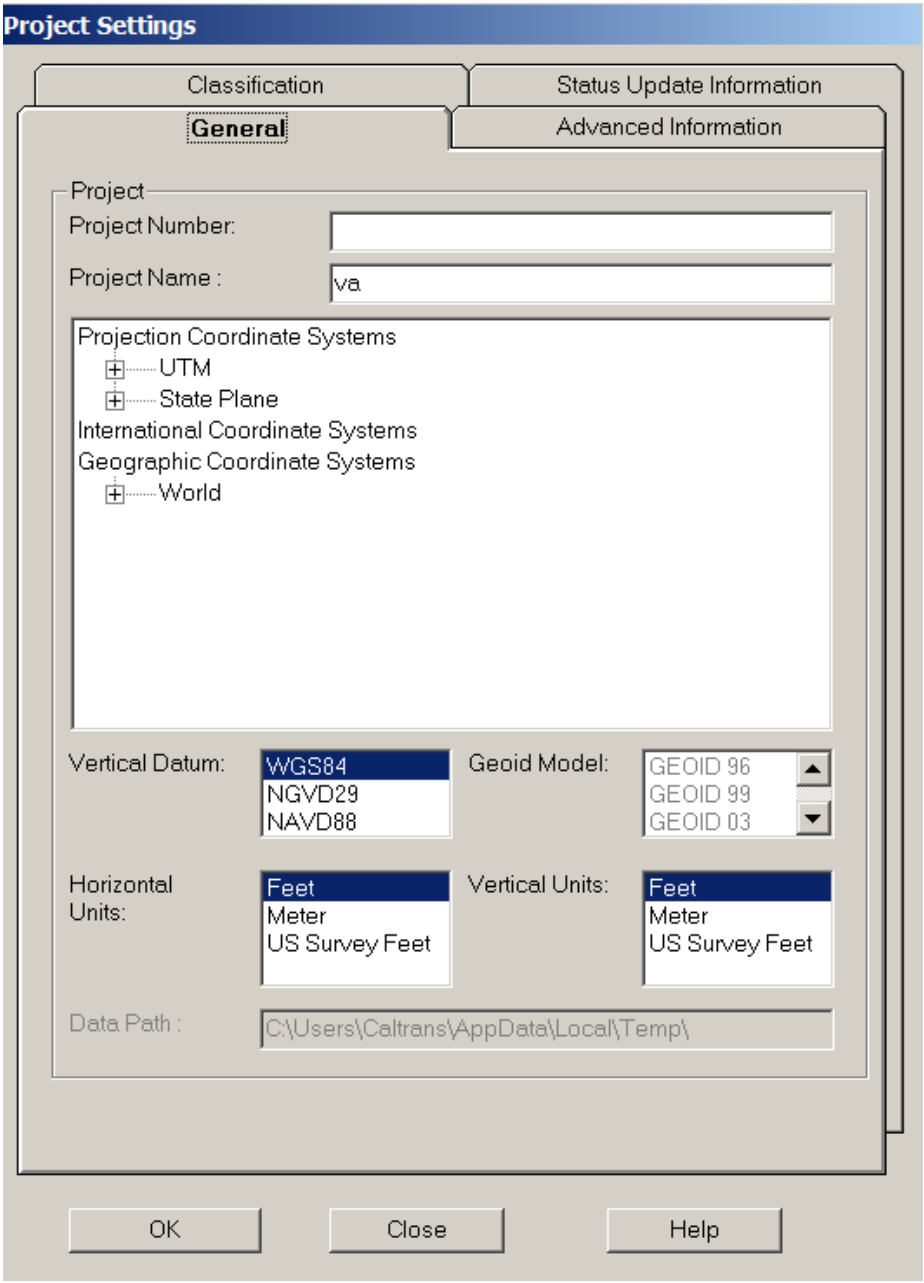


Figure 6: Project Settings Window

The project settings have 4 tabs: Classification, Status Update Information, General, and Advanced Information tab.

General Tab: This tab is used for assigning project number, project name, and units to the project.

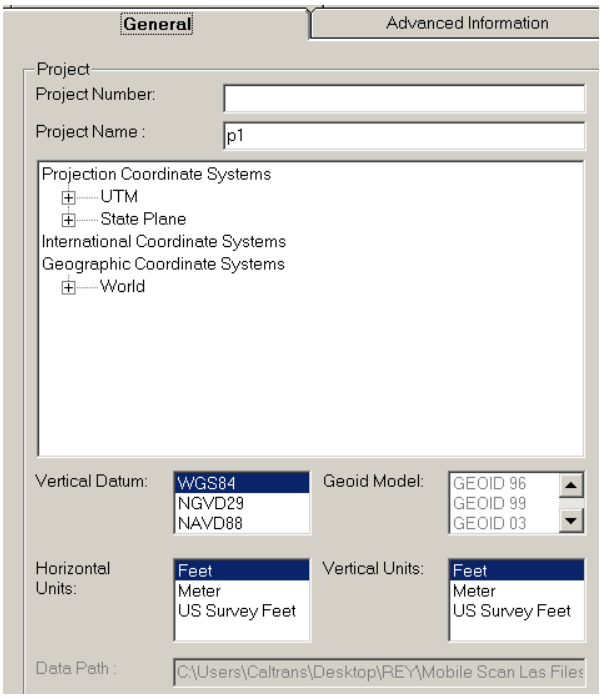


Figure 7: General Tab Option

Classification Tab: This is used for including the Feature codes for all the various features like vegetation, buildings, water and so on. One may also define custom Class Features and import the file as a .txt file.

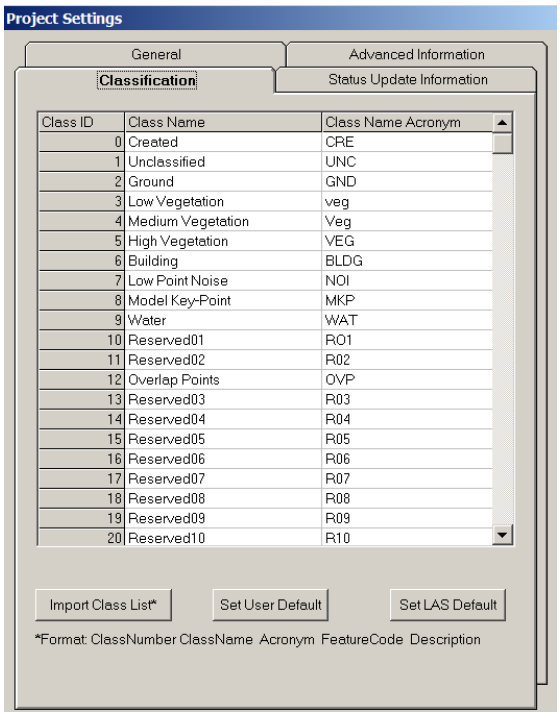


Figure 8: Classification Tab having a custom defined class list

Status Update Information: This is used for assigning ID's to various Status updates

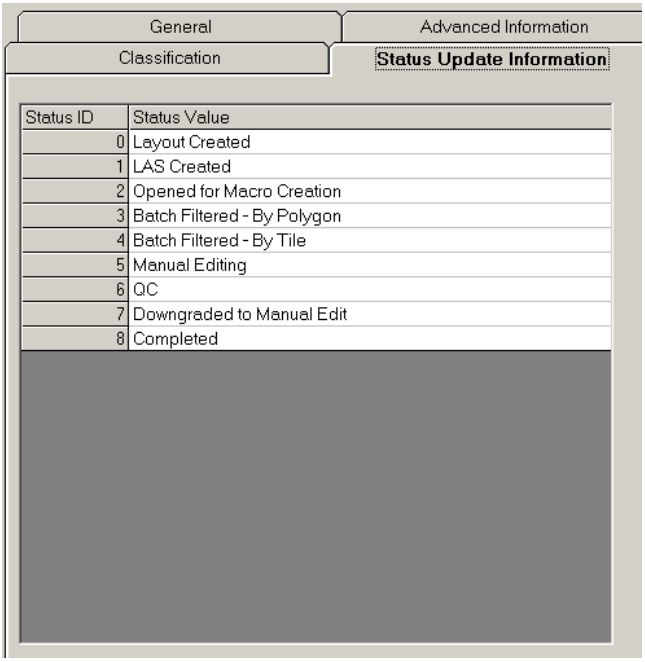


Figure 9: Status Update Information Tab in Project Settings

Advanced Information: This tab is used for specifying project details like project manager, accuracy, metadata, contours, project type, and project duration. The project type can also be changed using this tab.

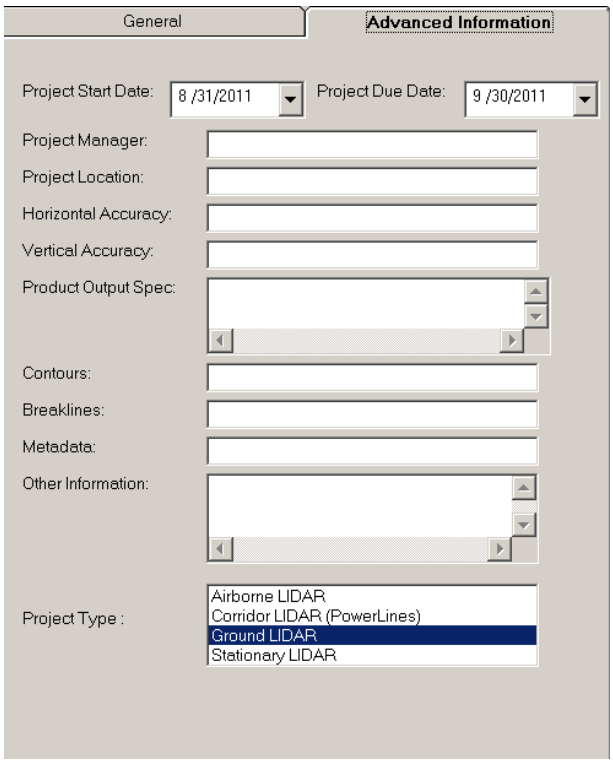


Figure 10: Advance Information Tab

Importing a Line-Strip Bounds or an LAS file

- The user can import the LAS files using the Import Line-Strip Bounds tool and the software creates a boundary shape file that wraps around the imported LAS files

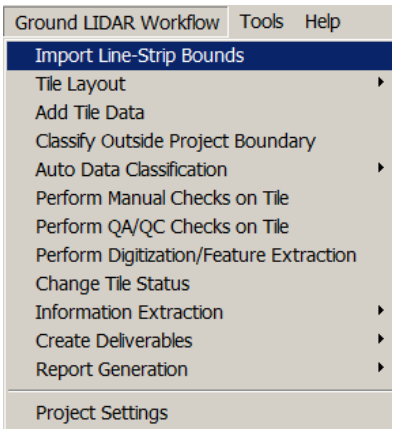


Figure 11: Importing Line Strip

- After importing the Line-Strips, the Layer can be right clicked on, select Open Attribute Table and LAS file attribute can be viewed

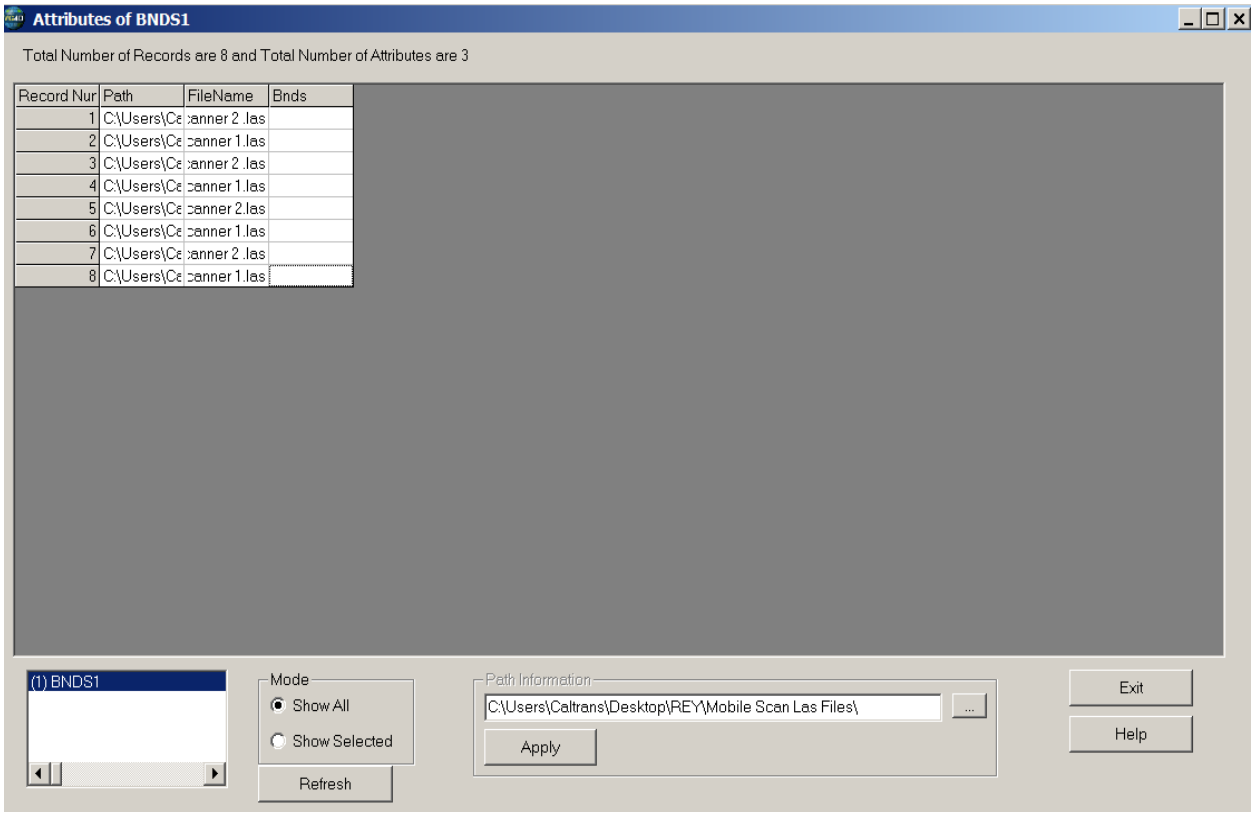


Figure 12: Attribute of Imported file

- Once the strip is imported, make sure to check the box on the left side and make it active layer as shown below.

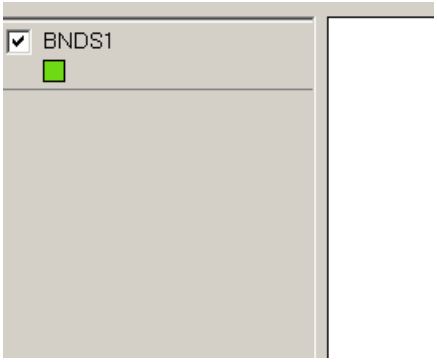


Figure 13: Active layers in Analyzer

NOTE: If the strip is not selected, it would not be visible. If the strip name is not clicked/made active, it cannot be opened in the viewer. Hence make sure to check the strip for visibility and make it active by clicking on it.

- Addition of layers or more strips can be done by clicking on Layers ->Add layers. Similarly removing of strips can be done by selecting them and clicking on Layers -> Remove Active Layer

Tile Layout Tool

Tile Layout Tool is required when dealing with large size LAS file. It enables the project manager to deal with the required section of a big scan file. Further, the macros (which will be described in next chapter) can be used to run on a small tile and further extended to the entire LAS file which requires less time and hardware.

- Select Ground LIDAR Workflow and click on create Tile Layout

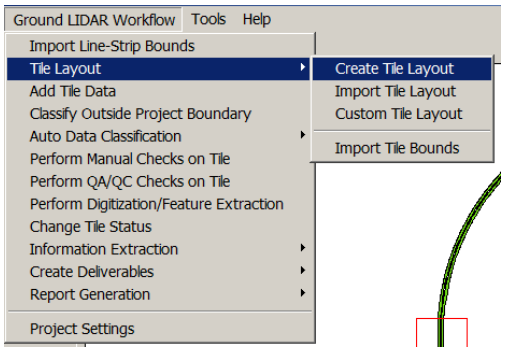


Figure 14: Create Tile Layout

- A window opens on selecting Create Tile Layout as shown below:

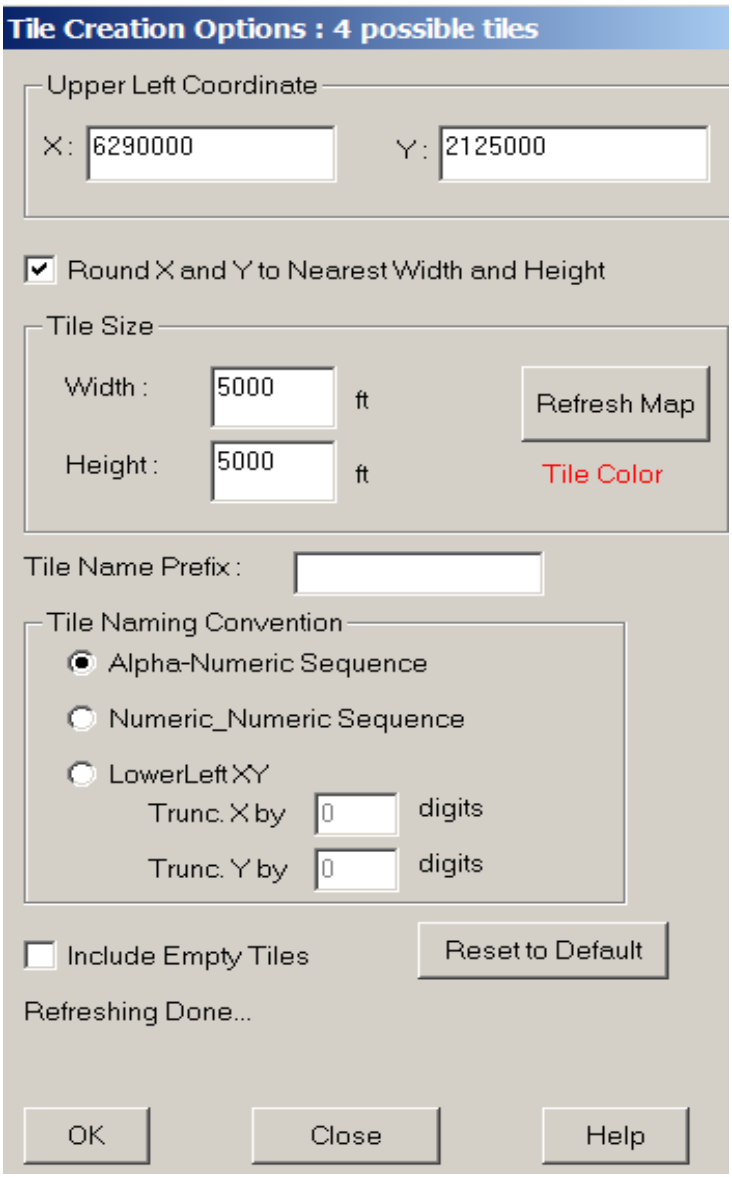


Figure 15: Tile creation toolbox

- The Width and Height of tile can be changed. Check the box 'Round to Nearest Width and Height' if nicely evened coordinates are desired
- Change Tile color as required
- Name the tiles alphanumerically (ex A1, A2, A3…B1) or Numerically (ex 1_1, 1_2, 1_3, 2_1, 2_2 …)
- After the tiles are created the analyzer would display a window as shown in Figure 16

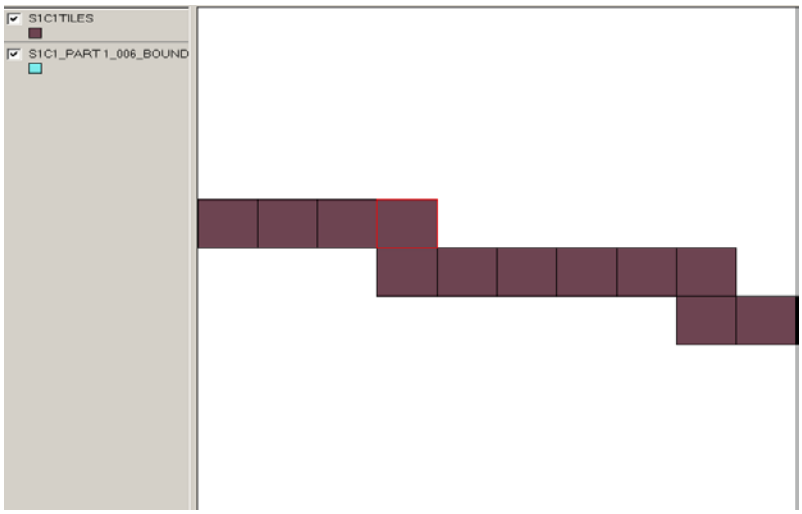


Figure 16: Created tiles as a separate layer

- After the creation of tiles, it is required to associate the tiles with LAS file. For this, Select Ground LiDAR workflow-> Add Tile Data and specify the path of the same LAS file for which tiles are to be created. Note that the output folder for the tiles, the shape file, project file as well as the LAS file should be in same folder in order to avoid the mismatch of file paths.

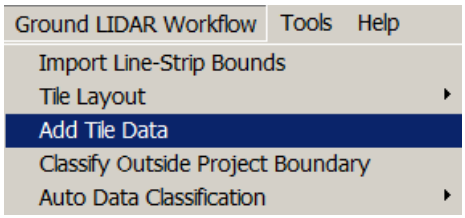


Figure 17: Linking Tiles to Data

- Once the files are associated with the tiles, make the tile layer active and click on  to select any tile and open its corresponding LAS file in Viewer

NOTE: *In case there is a gap between the flightlines of a single project, it may be helpful to create empty tiles between the gaps in data. One may also Import a Tile Layout (requires a shape file) or Create a Tile Layout which is very useful in not creating tiles with little or no data (Refer to figure 18)*

Before we move on to other parts of the workflow, it is important to learn the various Analysis Tools in Analyzer.

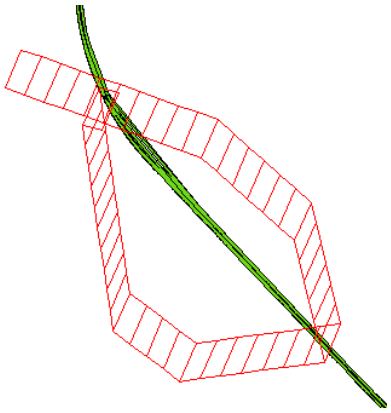


Figure 18: Custom Tile creation in Analyzer

LAS Information Viewer

This tool reads the LAS header and displays general information about the LAS file.

- Click on Tools in the Menu bar and select LAS information viewer
- Specify the path of the required LAS file. A table opens which has 3 tabs: Header Information, Statistical Information, and Projection Information. These tabs give information pertaining to the LAS file like Minimum and Maximum values of X, Y, Z, Intensity, Projection Type and GPS time which turns out to be useful in project management for large size LAS files involving multiple strips. If the points are classified it would also display the percentage of ground and vegetation which would be seen in the form of pie chart in Class Distribution

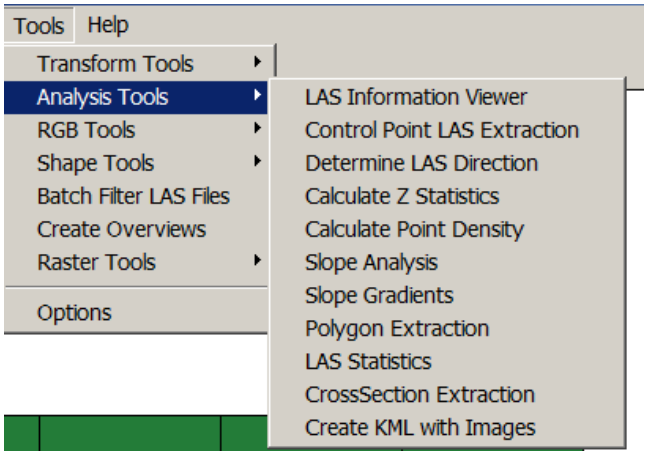


Figure 19: Analysis Tools in Menu bar

- This data can also be exported as a text file

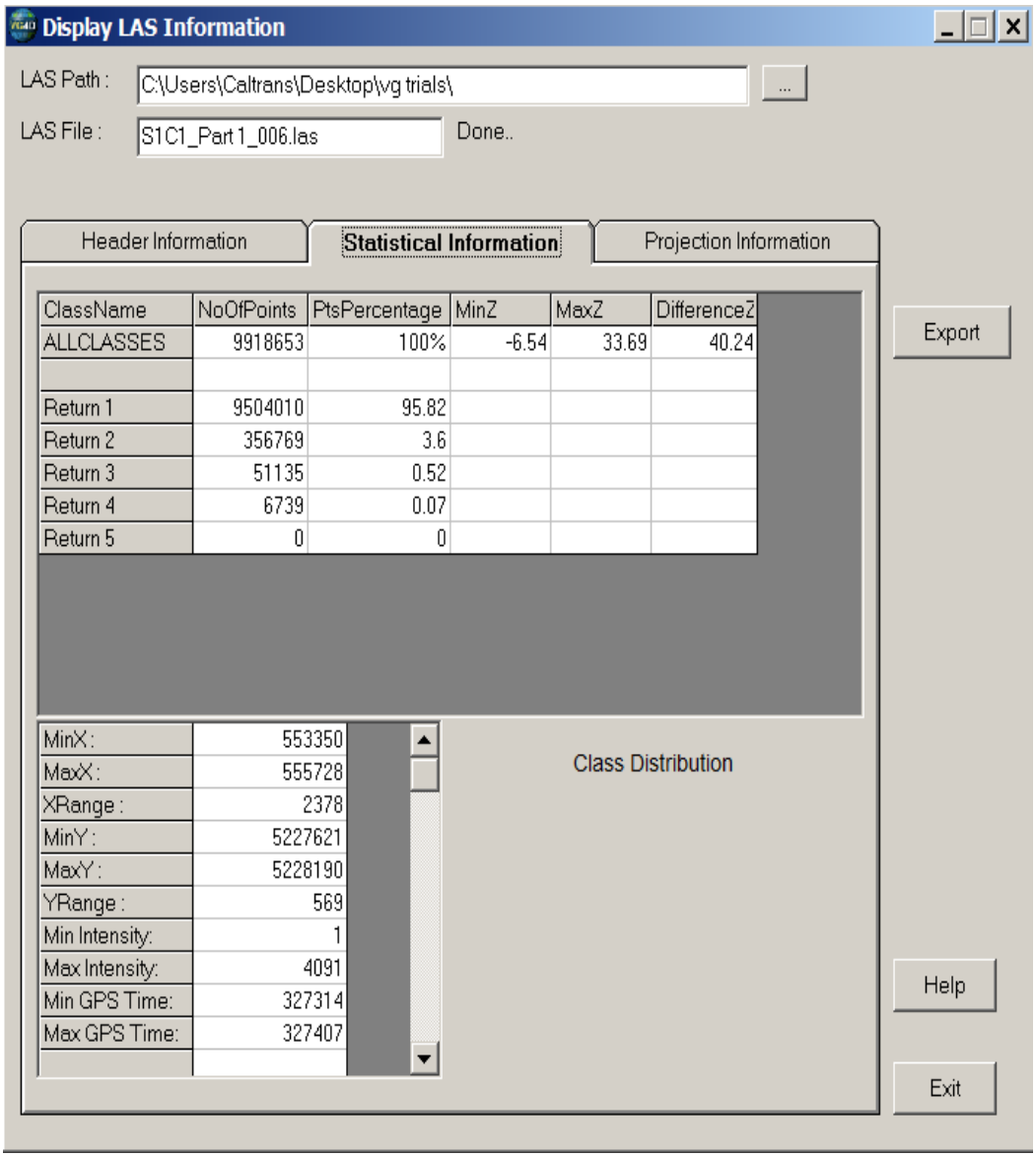


Figure 20: Displaying LAS information

Control Point LAS Extraction

The Control point extraction tool will create a small LAS file with each control point, from the provided control point file, embedded into it. The control point file must be in Point ID, X, Y, Z format with either space or comma delimiters. The LAS file then can be opened in the 3D Viewer and the location of the control point relative to the point cloud data can be inspected. The buffer distance is the size of the LAS file created.

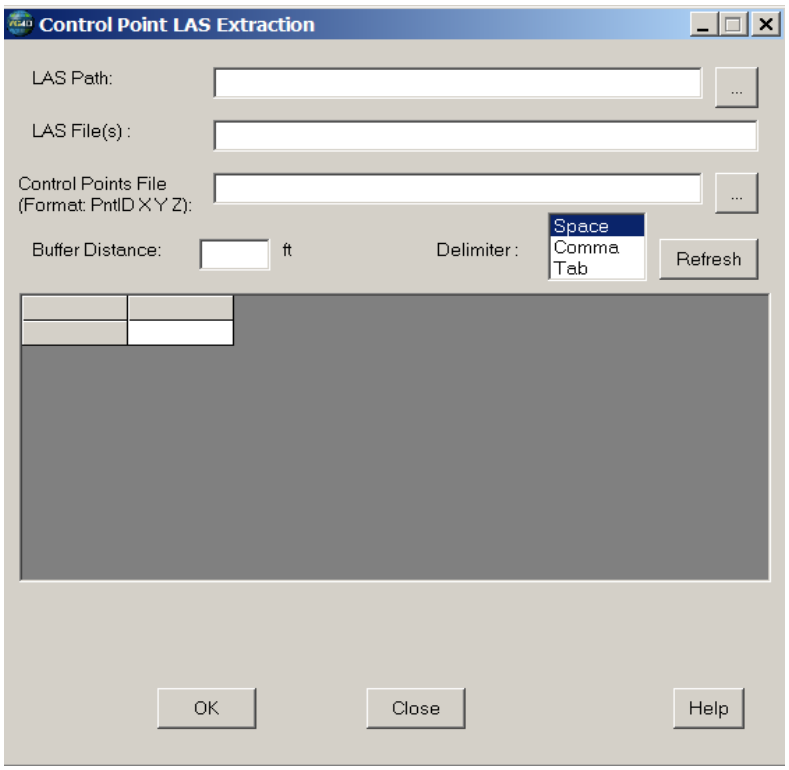


Figure 21: Control point extraction

- Click on Menu bar -> Tools -> Control Point LAS Extraction. Specify the path of LAS file along with the path of Control Point file location, buffer distance and delimiter.

Determine LAS Direction

Select flightline LAS files and this tool will determine the flightline direction and export that information to a text file.

- From the menu bar, choose Tools -> Analysis Tools -> Determine LAS Direction as seen below:

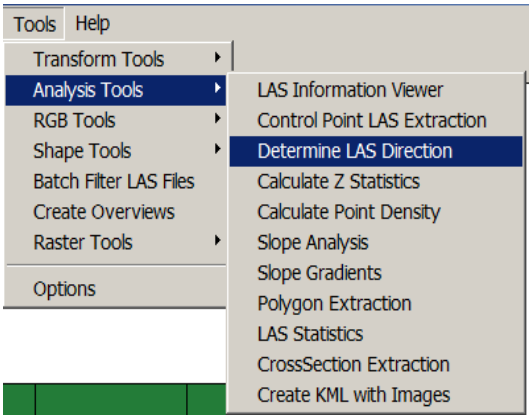


Figure 22: Finding LAS Direction

- A dialog box opens as seen below. Specify the path of LAS file and Output file (as .txt file)

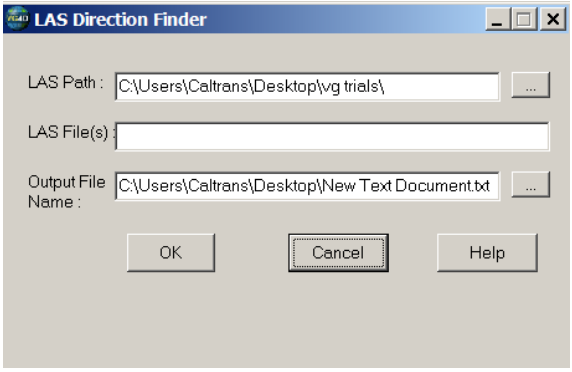


Figure 23: LAS Direction finder

Calculate Z Statistics

This is used for finding out the Z statistics (Overall Min. and Max. values) for a particular class or complete LAS file.

- Select Tools ->Analysis Tools -> Calculate Z statistics
- A dialog box opens as seen below:

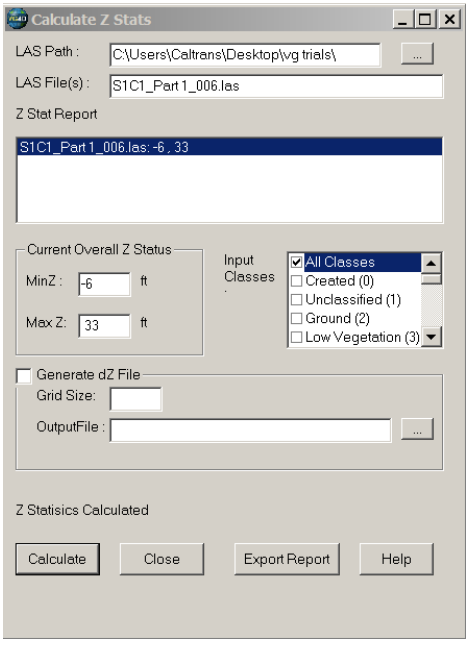


Figure 24: Toolbox for Calculating z stats

- Specify the Path of LAS file, the input classes and click on Calculate to view the Z stats. The differential dZ can also be viewed by same method.
- The results can be exported as a text file by clicking on Export Report

Calculate Point Density

This is used for calculating point density.

- Select Tools ->Analysis Tools ->Calculate Point Density. A dialog box appears as shown below:

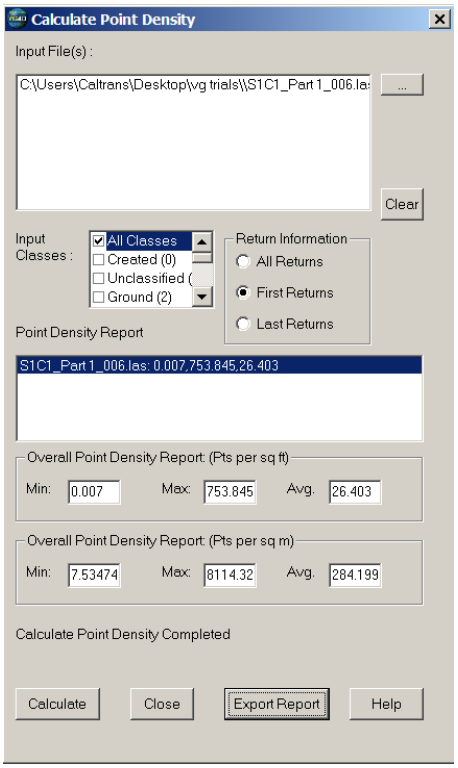


Figure 25: Calculation of Point Density

- One may also select a particular class for which the point density is required to be calculated.
- The point density can be exported as a text report with the displayed information above by clicking on Export Report

LAS Statistics

This is used for calculating the complete statistics of the LAS files like minimum X, Y, and Z

- Select Tools ->Analysis Tools ->Generate LAS Statistics. A dialog box opens as shown in Figure 26

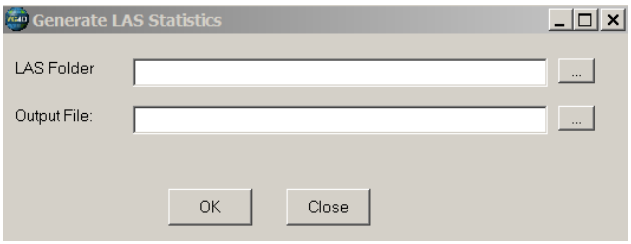


Figure 26: Generation of LAS Statistics

- Specify the path of LAS file and output file name.

Cross Section Extraction

This tool is used for creating cross section using LiDAR Analyzer

- Select Tools ->Analysis Tools ->Cross-section Extraction. Specify the width and length of Polygon Strip size in the dialog box as shown below.
- One may also draw a line along which cross sections are desired by clicking Draw line and drawing the line in Analyzer over the strip

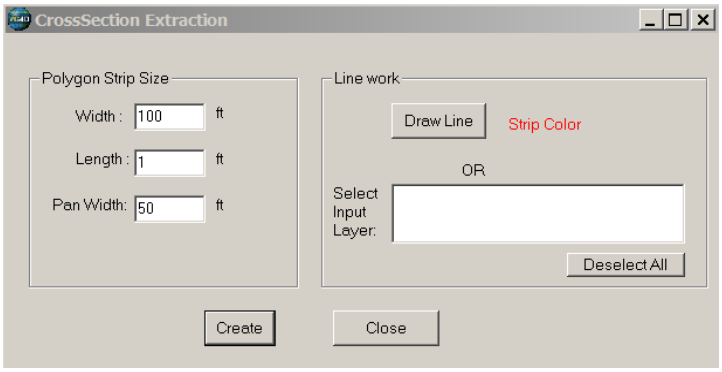


Figure 27: Cross section extraction

- After drawing a line the cross section as visible in the strip is shown below:

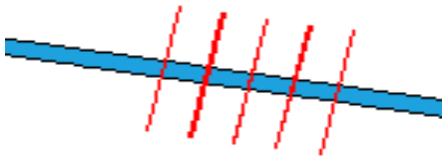


Figure 28: Created Cross Section as seen in Analyzer

- After creating the lines, you may want to specify the name of the shape file for saving the cross section

- The cross-section would be visible as a separate layer in the Analyzer as shown below

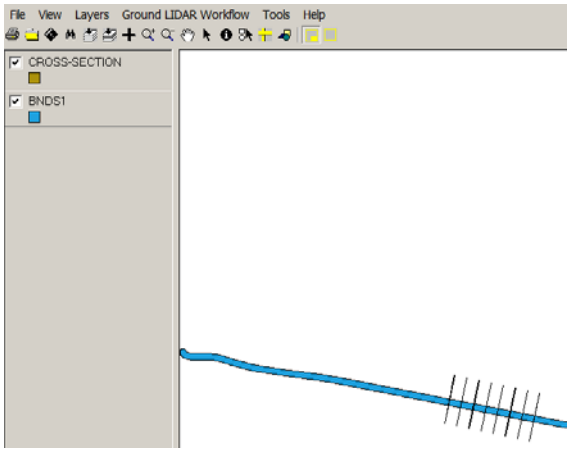


Figure 29: Cross section layer in Analyzer

Export to KML with Image

This is used to for exporting an image file as a KML in Google Earth.

- Select Tools ->Analysis Tools ->Export to KML with Image

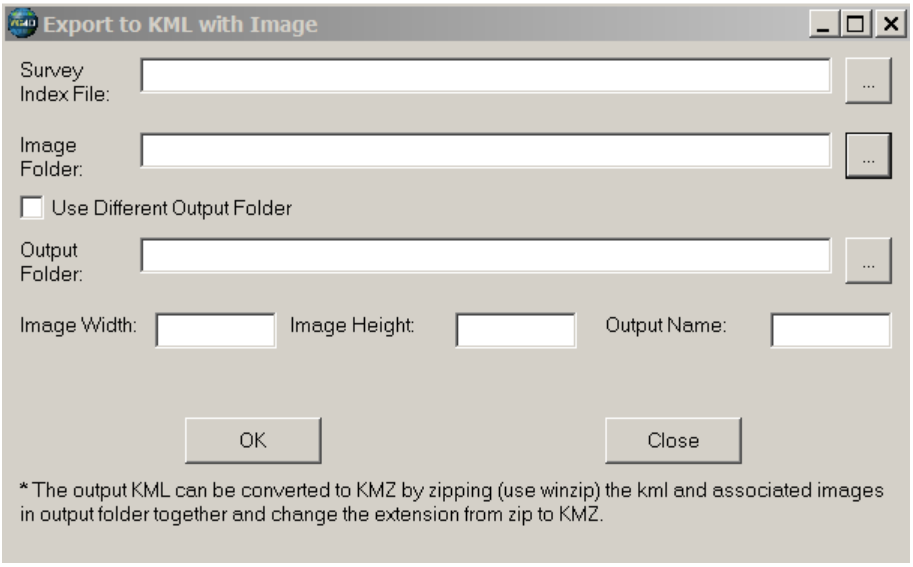
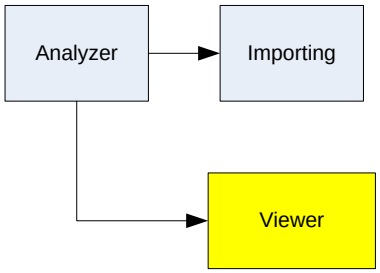


Figure 30: Export to KML toolbox

- The user must have the survey index file and image folder to be specified for using this command which are to be specified in the dialog box along with the output folder and image requirement. The image width and height can be selected from standard sizes: 320×200, 640×480, 720×348, 1024×768, 1280×1024, 1366×768, 1600×1200, and 1920×1200

Chapter 3: LiDAR Viewer



VG4D has a free, easy-to-use, 3D, fully interactive, LiDAR viewing tool which is capable of various features as described in this tutorial. The main features of this are:

- Powerful and easy-to-use 3D data viewer
  Rapidly visualize point cloud data for display
  Profile / cross-section view
  One-button classification visualization
  Visualization modes include:
    - Shaded relief
    - Elevation
    - Return
    - Intensity shading
    - Color by classification
    - Color by flight line
    - Pseudo contours
    - LSF - LiDAR Spectral Fusion
- Intuitive 3D rotation
    - Panning
    - Zoom
    - Vertical exaggeration
    - Azimuth
- On-the-fly TIN rendering
- On-the-fly 3D contour visualization
- GPS time, coordinate, return, intensity and filename readout by cursor location
- Stand-alone; no 3rd party software required
- Save high resolution screen shots
- LAS 1.1 and 1.2 compliant

Starting 3D Viewer

Invoke VG4D- Viewer by Tile – Select a tile to view point cloud in the 3D viewer. The tile will be opened in the 3D viewer with filtering and editing functions depending on the tile status in the project lifecycle/workflow.

If enabled, the Open Independent Viewer icon will be present in the 2D Viewer's Menu Bar that will allow the user open an independent viewer. The user will have to browse for LAS files to open and this viewer will have filtering or editing functions available but the status of that tile will not be tracked. If not enabled, it can be done by:

- Click on the Tools -> Options in the Analyzer Menu Bar

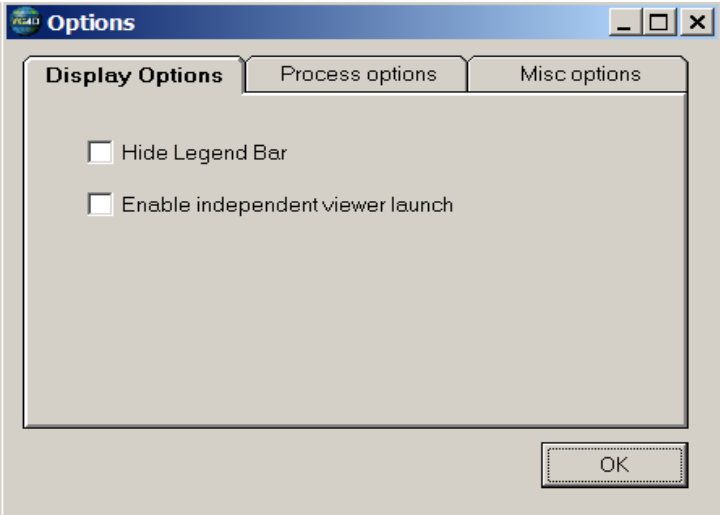


Figure 31: Enabling Independent Viewer Launch

- Select Display Options Tab and Check on Enable independent viewer launch

3D Viewer Menu Bar

The Options in the Menu Bar are *File, QC Redlining* and *Help*. The file tab has the following options each of which is described as below:

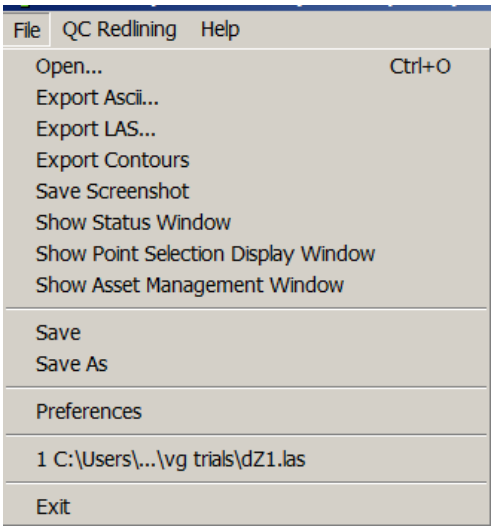


Figure 32: 3D viewer Menu bar

Open: Browse and select any LAS file to open

Export ASCII: Export the currently viewed points to an ASCII file. Useful for exporting small areas

Export LAS: Export the currently viewed points to an LAS file

Save Screenshot: Save a high resolution screen shot of the data zoomed into in the view as a .tif file

Show Status Window: Calculates the file summary like Total number of points, Range of X, Y and Z. This can be further exported to a .txt file by clicking on the Export Status button in the Status Dialog.

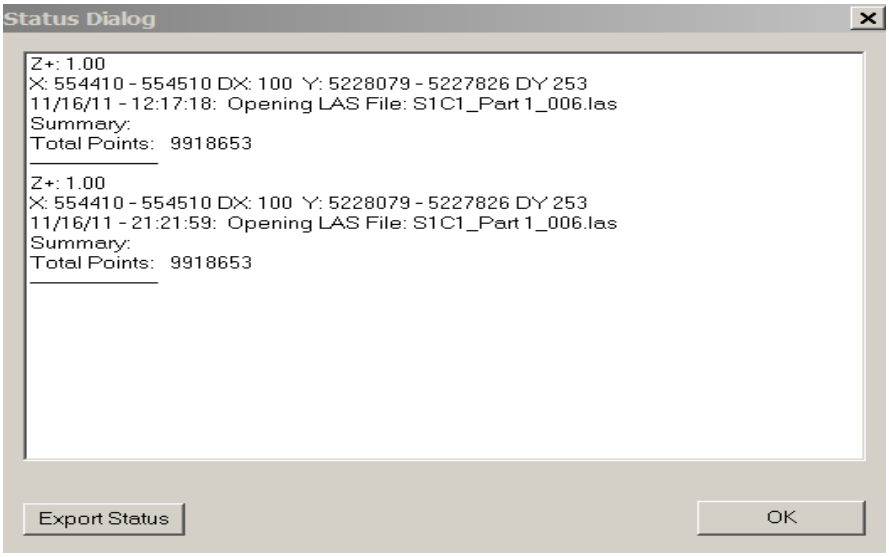


Figure 33: Status Window

Show Point Selection Display Window:

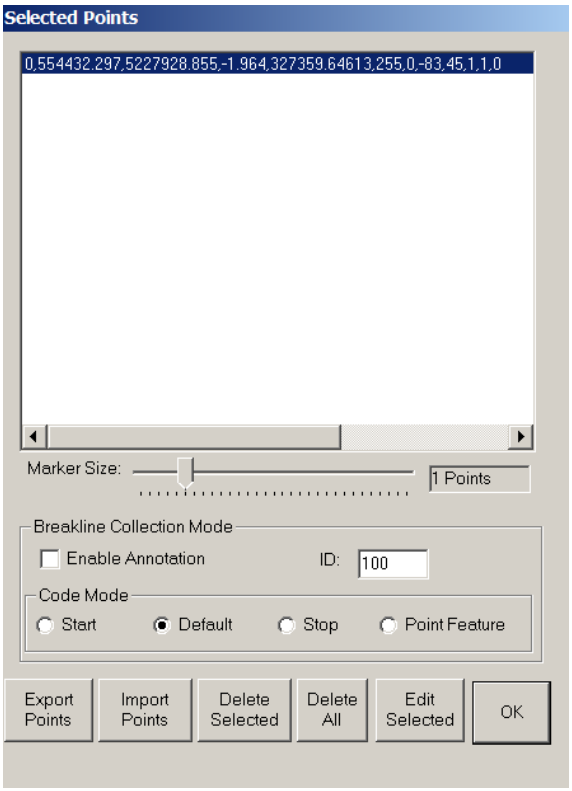


Figure 34: Point Selection Window

This window has several options which are described as follows:

- Marker Size (X): For controlling the size of marker used for selection of points
- The points selected can be edited using Edit Selected command. Similarly Delete Selected can be used for deleting the selected points
- One may also export points as .pts file using Export Points command. Similarly importing of points is done by Import Points and specifying the path of .pts file

Preferences

The Preferences window has several options. Most common ones are described below.

Point Size: For adjusting the point size for the viewed points cloud. This can be adjusted using the slider bar

Background: The background can be adjusted along the grayscale from Black to White using the Slider

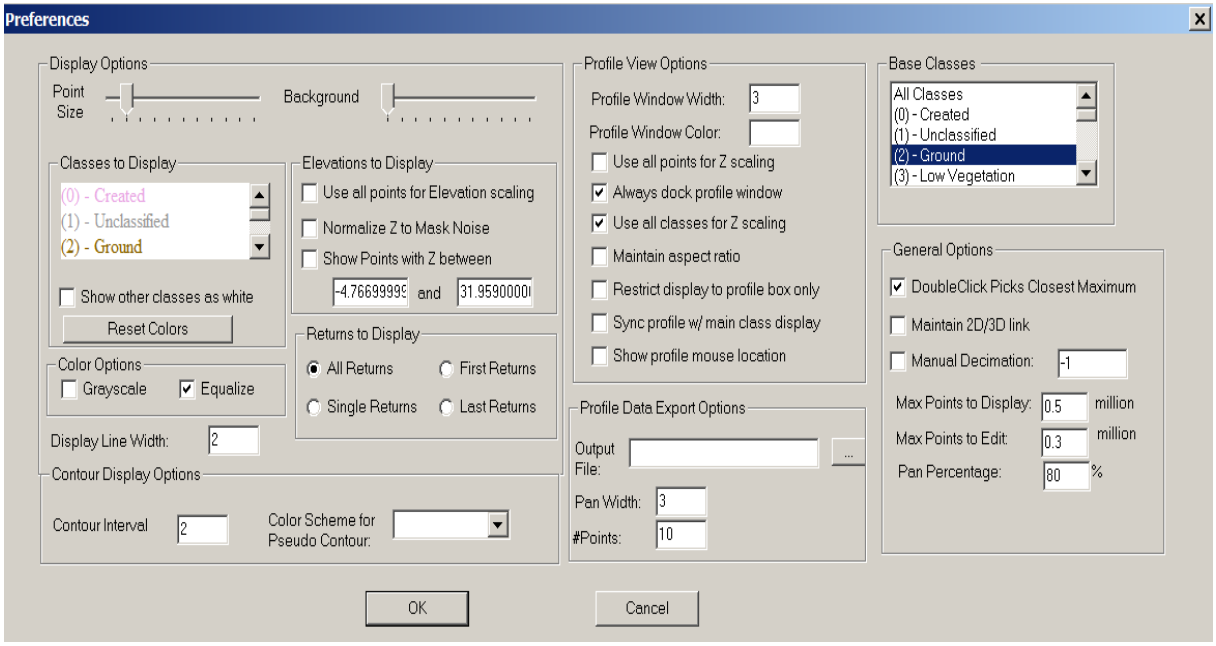


Figure 35: Preferences Option in Viewer

Grayscale: Toggle to change viewed point to grayscale. This is required in order to view shaded relief in grayscale. To enable it select Grayscale and Click OK

Equalize: Equalizes the spectral ranges in the LSF data. Please refer to the manual for more details

Normalize Z to Mask Noise: Masks the outlier elevation points when viewing point data allowing for a uniform view across a project. This option is widely used in ground LiDAR for extraction of ground surface.

Classes to Display: For selecting the Classes to be displayed

Show Other Classes as white: Classes that are turned off can be displayed whites. Select if white colored turned off points are desired. Selection can be done by clicking on the check box in Classes to display option.

Returns to Display: Selecting the points to be displayed depending upon their returns which are Single Returns, First Returns and/or Last Returns

Contour Interval: This identifies the interval for both displayed Pseudo Contours and Contours. Select the desired contour interval and color scheme

Profile Window Width: The Width of the profile window can be changed here after it is drawn manually by selecting the desired profile window width

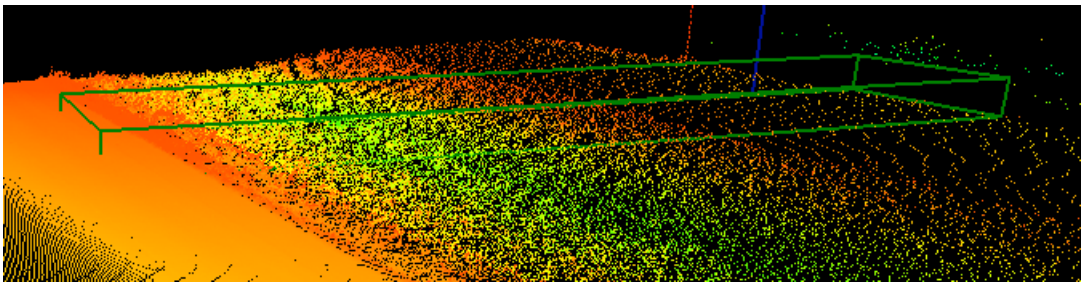


Figure 36: Profile Box (Green) as seen in Viewer

Restrict Display to profile box only: This option is to instruct profile viewer to display only the data that falls within the drawn profile window or display more data to fill the profile viewer screen. This is used especially when drawing a very small profile window and gives user option to see how much data they want to view

QC Redlining

This function is used for QC process. A shape file can be created or opened in the 3D viewer and problem areas can be identified spatially by drawing polygons. Remarks can be entered too if needed. The user can then open the redline shape file in the 3D viewer and drive to the areas in question and make the required fixes.

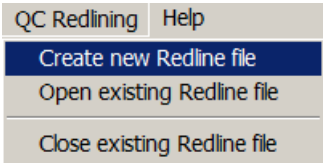


Figure 37: QC Redlining Pull down Menu

The procedure for the same is as follows:

- Go to QC Redlining -> Create new Redline file
- Name and Create a new Redline shape file, or open an existing redline file by going to QC Redlining -> Open existing Redline file
- In the 3D Viewer, select the Enter Redlining Mode button
- Draw a polygon around the points in question, double clicking to end the polygon

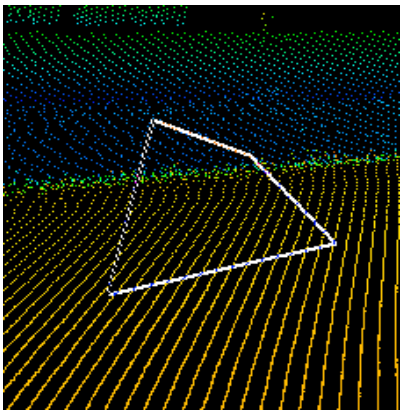
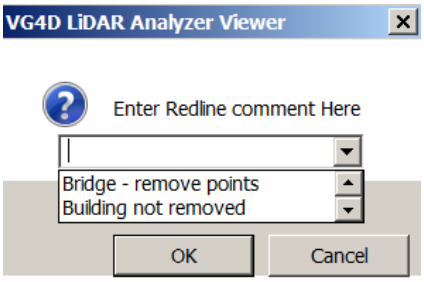


Figure 38: Polygon Drawn for Comment

- Enter comments into the text box (See Figure) and click OK



- Users can press Cancel to ignore or undo currently drawn shape
- The dropdown arrow will show a list of commonly used comments. However you may enter your own comments

3D Viewer Toolbar

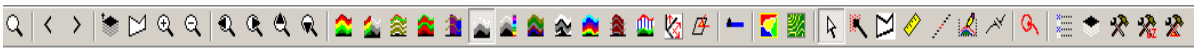


Figure 39: 3D viewer toolbar

The various icons in the toolbar are described as below:

 : Align to top view

 : Select polygon sub-area

 : Zoom In

 : Zoom out

 : Pan Left

 : Pan Up

 : Pan Down

 : Pan Right

: View by elevation

: View by Class (only if LAS data is classified)

: View by Return

: View by File (This function will color by file ID)

: View by Intensity Image

: View by LSF

: View by Shaded Relief

: View Pseudo Contours – Color modulated by elevation interval

: View Buffers (Used only if buffers were created for tile data)

: Reclassify LSF

: TIN (Turns on the on-the fly TIN rendering)

: View Contours (on-the-fly contour rendering)

: Normal Viewing Mode

: Manual Edit Mode

: Select Polygon subarea to Filter- Creates an area to contain filtering activities for testing filters. Single left mouse click to draw polygon double left mouse click to end polygon

: Ruler- Right Click and drag. Watch the lower left corner of the 3D Viewer status bar for the distance and elevation difference

: Profile Mode – Opens Profile viewer for viewing and editing

: QC Redlining Mode (for enabling the QC redlining function)

: Select Classes – Opens the Select Classes Window

: On-the-fly Settings – Opens the On-The-Fly Settings window. Azimuth, Elevation, and Z Exaggeration (Hot Keys also available) slider bars and options for moving the profile box in the main viewer during profile mode

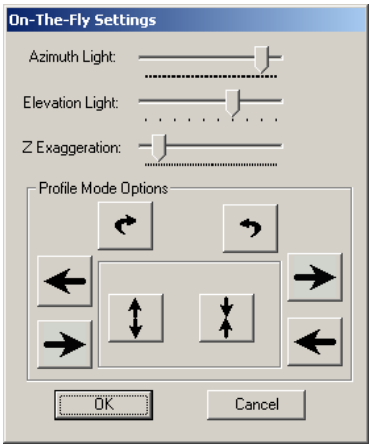
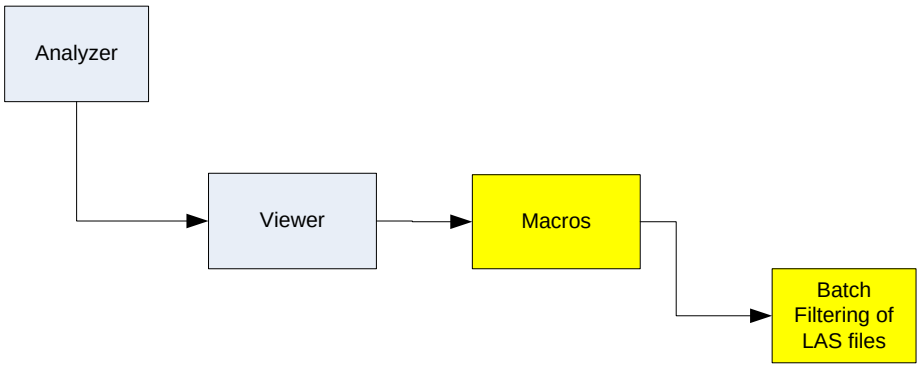


Figure 40: On the Fly Settings Window

Chapter 4: Macros and Filters



VG4D Production Manager Filters

The VG4D Production Manager software is equipped with fully customizable filters. Simply select the filter and click Run Selected Filter to open the filter and set its parameters. The filters are generally listed in the order they would typically be used within a Macro. To learn how to create Filter Macros, refer next section.

Figure 41: 3D Viewer Filter Toolbar

Filters in VG4D Viewer

Reclassify Points

This filter is used to change the classification of points. It is a good practice to run this filter first in a filter macro to make sure all points have been classified to the same class.

Parameter	Defined	How to Use
Input class	The class or classes to be reclassified	Select the classes that need to be reclassified
Output Class	The class that reclassified points will be assigned	Select the class that the points will be reclassified to

The first step before implementing any filter would always be reclassifying all the points to a common class

- Select All Reclassify Points from List of Filters and Click on Run Selected filter in the LiDAR viewer. A dialog box opens as shown below:

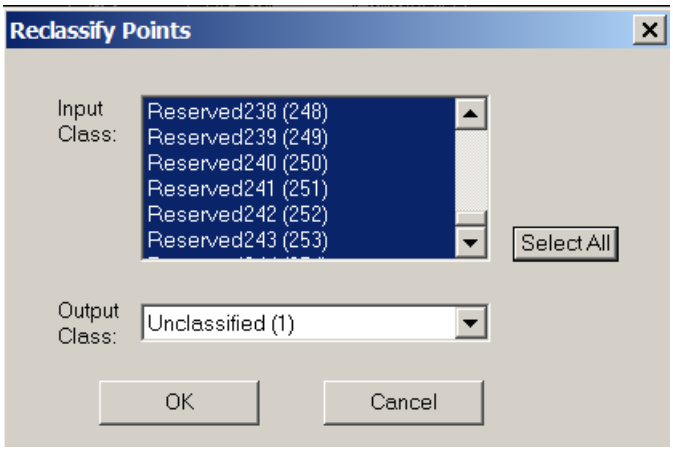


Figure 42: Reclassify Points using Filters

- Click on Select All and specify the name of the desired output class. In this Ground class is chosen but it is completely dependent on the user
- Click on  icon. A dialog box appears as shown in figure below
- Click on the class which was specified as output class
- Select the  icon to view the points by classification

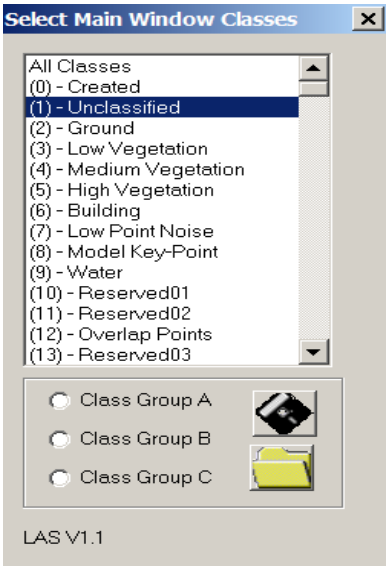


Figure 43: Classification Selection Tool

- The selected class (which is unclassified ground class in this case) will appear as seen in the figure below:

Figure 44: Point cloud classified to a ground class

Ground Filter

This filter is designed to be an easy to use filter for finding ground. It works on all terrain types and low and high points are also automatically filtered out.

- Click on the Airborne : Ground Filter
- Select the aggressiveness of the point filtration. The more aggressive, the more accurate is the filtration process but it takes time
- Select the appropriate Data type, Units of the data and terrain type
- Input Class identifies the class or classes where the points needed to perform the classification currently exist
- Select the class where the Non-ground Points will be moved to
- Select the class name to assign to the points that meet the ground criteria. It is recommended to use the class ground for this
- The option Building Size is only used to identify points that are particular structures or bridge columns. Min Z Threshold is also an advanced parameter which is used to specify the Z threshold based on elevation resolution of the data to gather valid ground points. It is available if **Manual** if selected. Similarly Max Z Threshold is based on elevation resolution of the data to identify non-ground points.

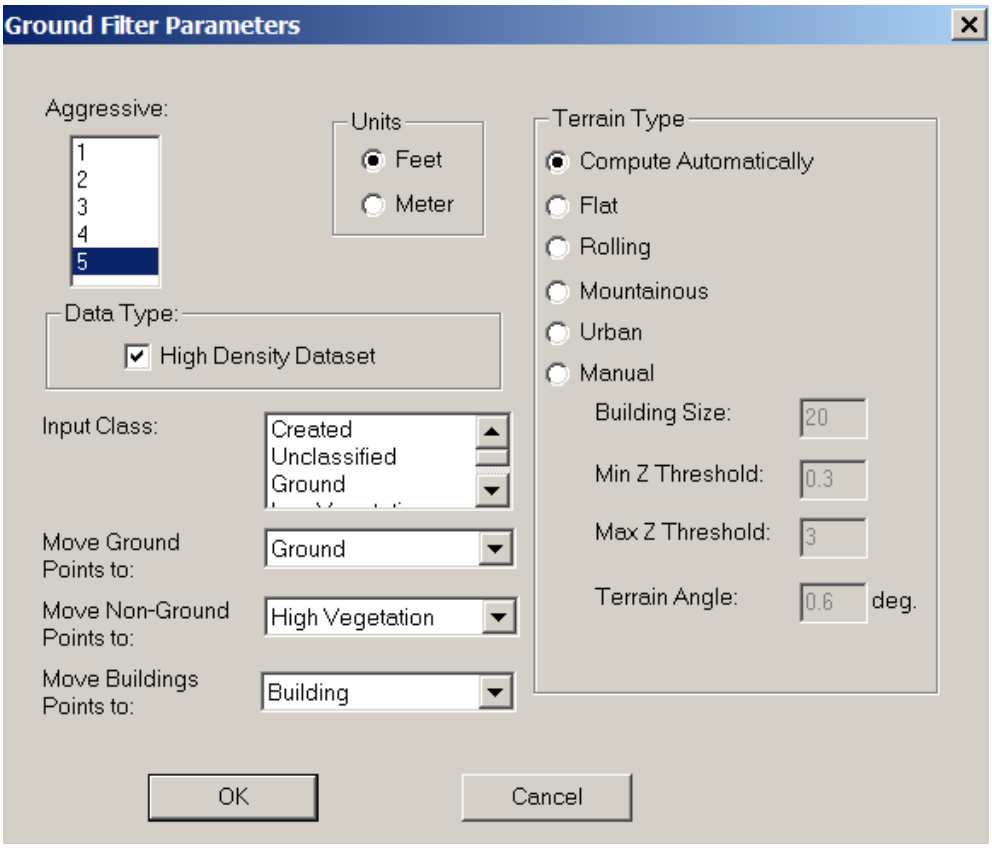


Figure 45: Ground Filter

- After using this filter, click on Selection tool to select just the Ground class with just the ground surface!

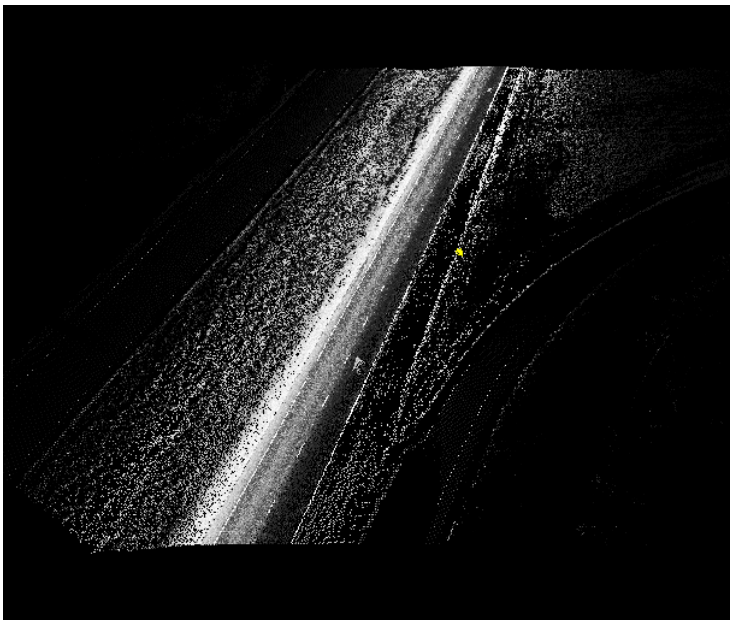


Figure 46: LAS file with ground filter implementation

Mobile Road Surface Extraction Filter

This filter is used for extracting the road surface with all the features like lane line and curb line.

- Select Mobile Road Surface Extraction Filter from the list of filters
- Select the Aggressiveness required along with the units
- Specify the Input Class (which would be ground class in this case) and the class to which the Non-Road Surface Points will be moved to
- Click on Ok. Select Classification Tool and highlight the Ground Class from the list to view just the road surface

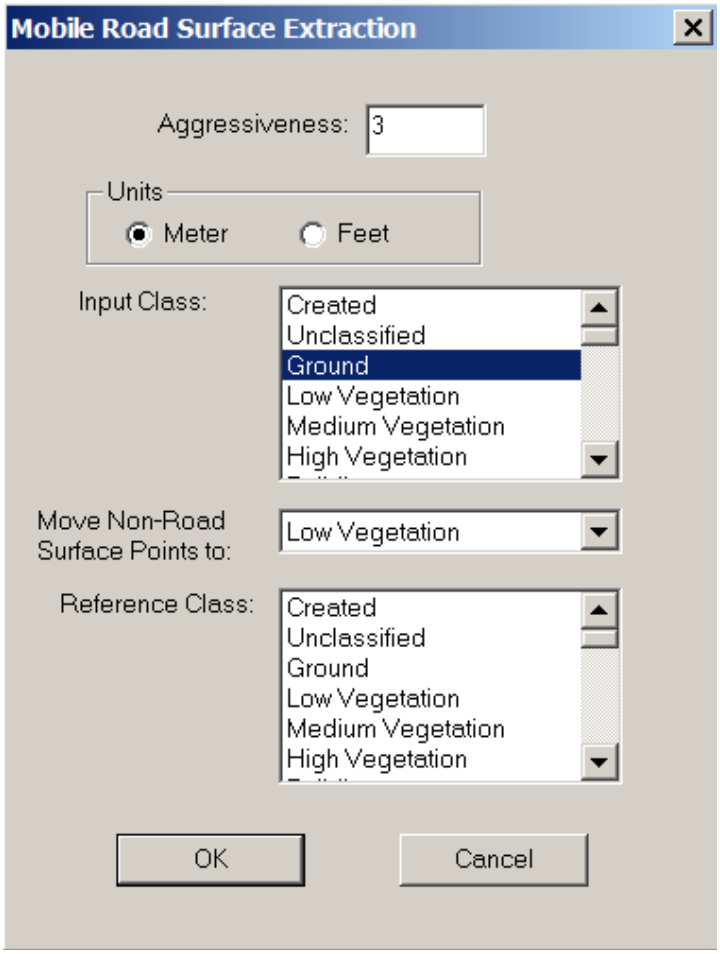


Figure 47: Filter for Road Surface Extraction

- If you select the All classes option and color points by classification from the toolbar, you may now see the classified road surface

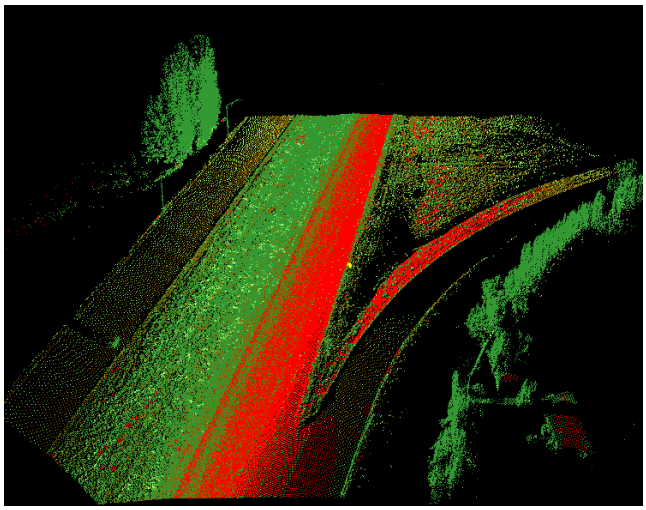


Figure 48: Road surface after classification

NOTE: If a filter is run and the results are undesirable, click **Undo Last Filter Step** in the Filter Toolbar

Other Filters

There are other filters also besides the one described above. The user is requested to read the manual for further explanation.

- *Vegetation Filter*: This filter classifies LiDAR points by analyzing the elevation differences between neighboring points. Best used as a vegetation filter. Can also be used for classifying isolated points
- *Advanced Vegetation Filter*: This filter classifies LiDAR points by analyzing the minimum and maximum elevation differences between neighboring points. Works similar to the Vegetation filter. Instead of a static number of neighbors and a minimum elevation, this filter allows you to define a range of neighbors and elevation differences. Best used as a vegetation filter
- *Surface Fit Filter*: This filter classifies LiDAR points by analyzing the surface fit within the search area based on the elevation difference condition. This filter works well for rolling terrain. It can be used to classify buildings left behind after classifying vegetation. This filter might take away points from hills into hilltops in rolling terrain if the search size is too large and is good for final surface cleanup
- *Building Clean-up Filter*: This filter classifies LiDAR points by comparing the elevation difference between two classes
- *Classify Spatially Close Points Filter*: This filter classifies LiDAR points by analyzing the spatial 'closeness' of points within a minimum distance

- *Multiple Return Analysis Filter*: This filter classifies LiDAR points based on the return value of 1 through 5 or by first, last or multiple returns. Best used for classifying vegetation
- *Surface Speckle Filter*: This filter classifies LiDAR points by analyzing the percentage of neighboring points at the same elevation interval. Best used to remove surface noise after bare-earth filtering
- *Classify by LSF Filter*: This filter classifies LiDAR points based on the specified LSF color value range by band. Best used to isolate ground features based on 3-band spectral values
- *Classify by Flight-line filter*: This filter classifies LiDAR points by flight-line ID number. It is useful in the removal of bad or unnecessary flight-lines
- *LSF color Adjustment*: This filter enhances color values in LSF data. Good for enhancing shadow areas under vegetation to classify surface points. It will only change the spectral values of LSF points in the selected classes
- *High/Low Point Filter*: This filter classifies high or low points greater than or less than input elevation value for classification of outlier points. Best if used for small projects or single files since terrain will likely vary more in larger areas. This filter also could be useful on very flat areas too.
- *Model Key Points Filter*: Used to "thin" points to the minimum number of points needed to describe a surface
- *LAS Output Filter*: This function is typically used at the end of a Macro to output the filtering to a new LAS file leaving the original LAS file untouched
- *Adjust Z by Flightline Filter*: To adjust the Z values of an entire flightline by a constant increment

Building a Filter Macro

This functionality is only available in the 3D viewer, if the Viewer is invoked by tile. Used to build, modify or test a filter a Macro, Click the Macro Options button

Figure 49: VG4D Viewer Filter Toolbar

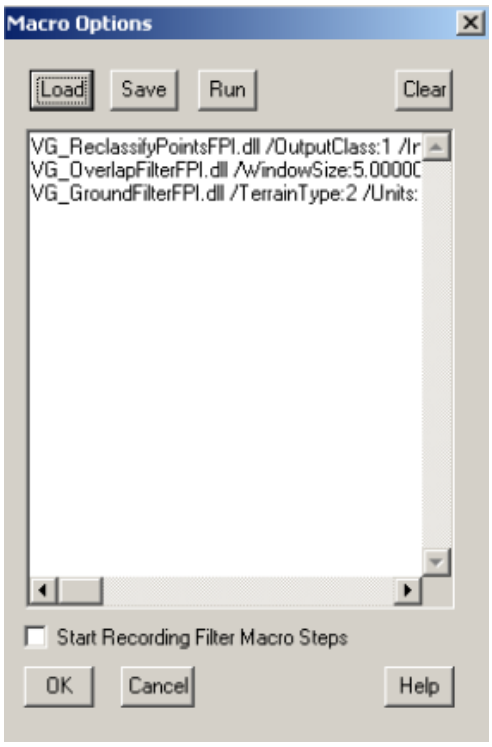


Figure 50: Macro setup

- In order to start recording a macro, click on Start Recording Filter Macro Steps
- An existing macro (.mac file) can be loaded using Load Function
- Save is used for saving the recorded Macro and Clear for clearing the Macro
- As the macro is being created, the macro can be tested by running it on selected data using Run function. The macro will only be run on the visible area in the viewer
- Once a macro is recorded, a saved macro can be run by clicking on Load and Run

Manage filter Macros

Once Filter Macros have been created and saved in the 3D viewer they must be cataloged in the VG4D software. This step is called Managing Filter Macros and is started by:

- Going to Ground LiDAR Workflow -> Auto Data Classification -> Manage Macros
- Click on Macro Path to browse for and select the macro file (*.mac)
- Go to Macro Name and give the macro a name and select Add Macro. The macro will appear in the Macro List
- Repeat for additional macros and click **Exit**
- It is recommended that notes are kept for how each macro was used because these macros can be reused or modified and reused in future projects

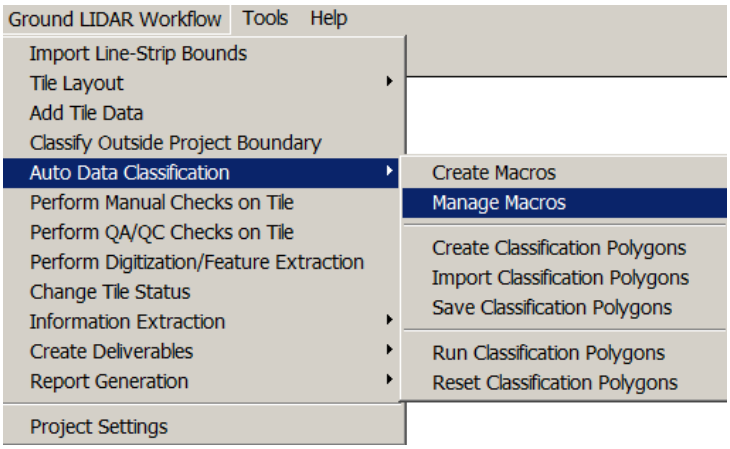


Figure 51: Managing Macros

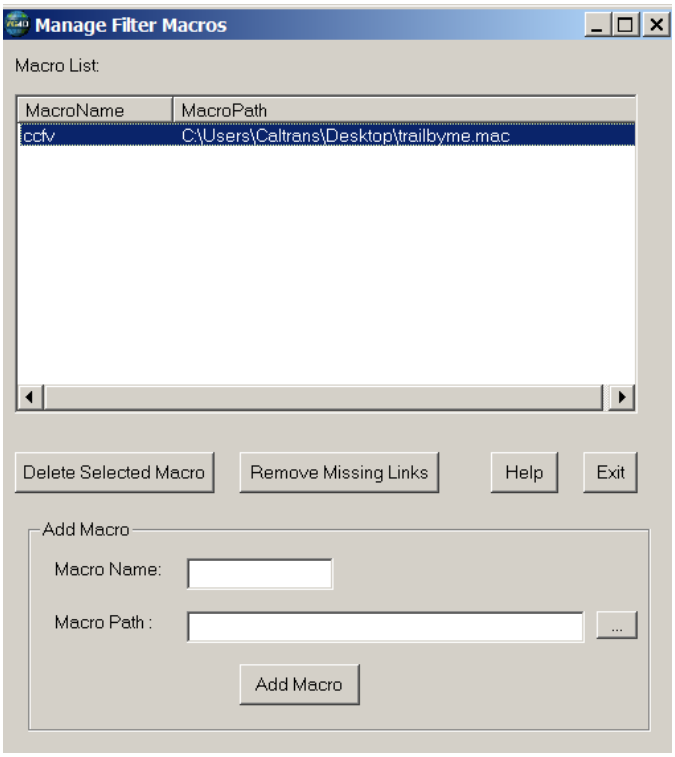


Figure 52: Macro Managing Dialog Box

Create Filter Polygons

The creation of filter polygons is a unique feature in VG4D. It allows the user to select very specific areas of a project to apply different filter macros. Reference imagery can be displayed in the background of the 2D viewer to help in this process. Often times different filter macros are needed for urban, forest, mountainous terrains, etc. This step will allow the user to efficiently and most effectively classify projects with different terrain types.

Create Filter Polygon Using Tile Boundary

There are two different ways to create a filter polygon; the first is to create it by tile boundary:

- Ensure that no other icon like tile icon is active
- Go to Ground LIDAR Workflow -> Auto Data Classification -> Create Classification Polygons

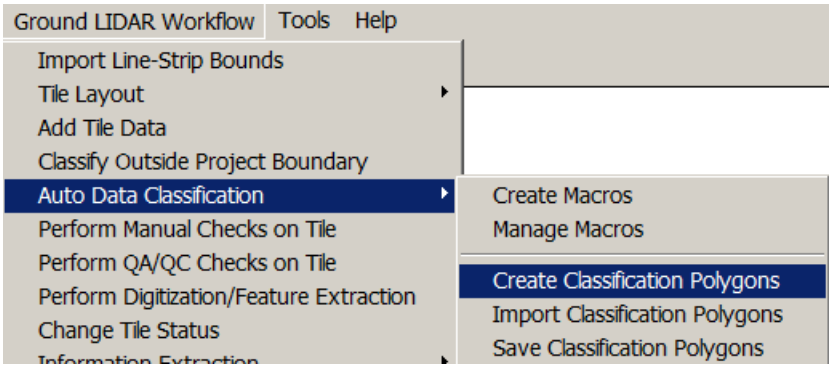


Figure 53: Creation of Classification Polygons

- Select the desired Filter Macro from the Select Filter window. This step must be done before the next step

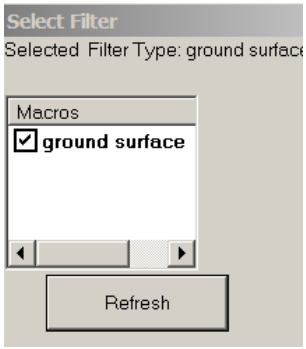


Figure 54: Available Macros for Batch Filter

- Select the Spatial Select button  in the 2D Viewer Toolbar
- Click and drag to select a continuous group of tiles or hold the CTRL key down and click tile individually
- Save the filter polygon by going to Project Workflow -> Automatic Filtering -> Save Filter Polygons. The software will prompt you to open the new shape file as a layer

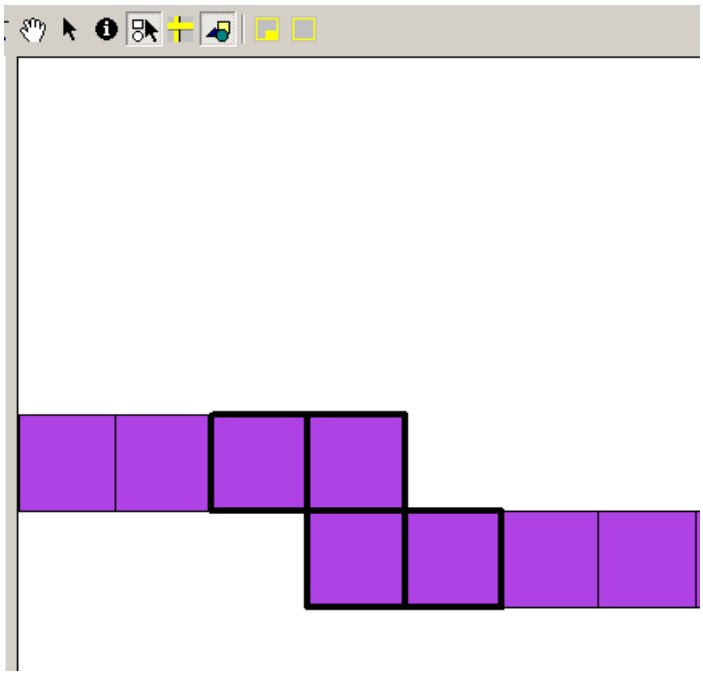


Figure 55: Create Filter Polygon by Tile Boundary

Create Filter Polygon using Graphics Tool

The second way to create a filter polygon is to draw the filter polygon in the 2D Viewer with the Graphics tool

- Go to Ground LiDAR Workflow -> Auto Data Classification -> Create Classification Polygons
- Select the desired Filter Macro from the Select Filter window. *This step must be done before the next step*
- Select the Graphics tool button  and the Pointer  in the 2D Viewer Toolbar.
- Draw a polygon by single clicking to place each node and double clicking to complete the polygon
- Save the filter polygon by going to Project Workflow -> Automatic Filtering ->Save Filter Polygons. The software will prompt you to open the new shape file as a layer i.e. a shape file

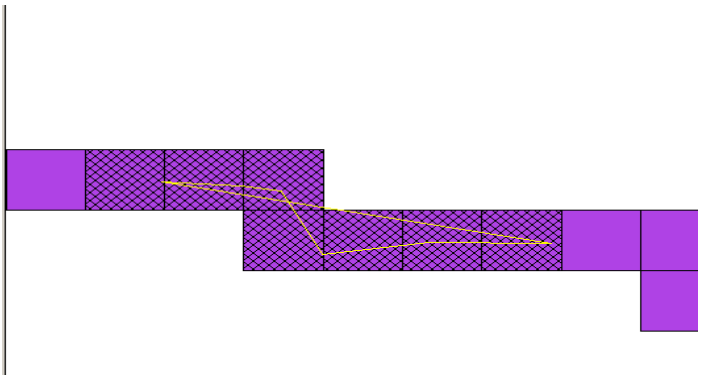


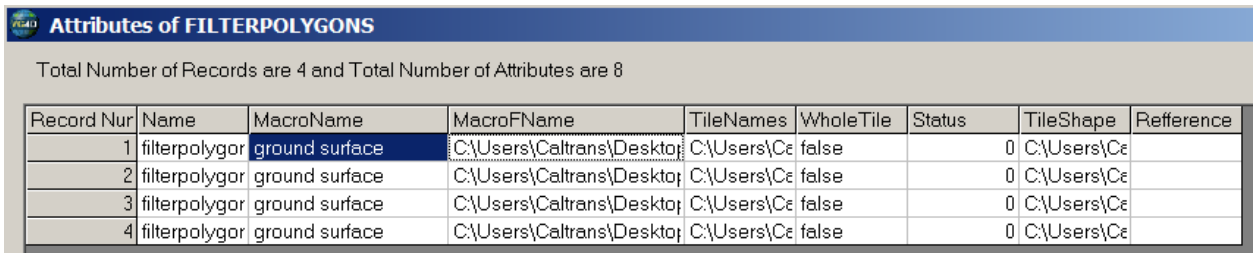
Figure 56: Create Filter Polygon by Graphics Tool

Save Classification/Filter polygon

- Multiple Filter Polygons can be appended. When saving the multiple filter polygons there will be the option of naming a new file or selecting an existing shape file in the project directory. If an existing shape file is selected the window will appear asking if the shape file should be Overwritten or Appended.
- One may also import Filter Polygons. For details please refer the help option or the user manual

Run Filter Polygons

- Highlight the Filter Macro layer in the 2D viewer then go to Ground LiDAR Workflow -> Autodata Classification -> Run Classification Polygons. Make sure the correct filter macro layer is selected. The message window will appear asking to start filtering. Select *Yes*. This process may often take more time depending upon the polygon and macro.
- As the tiles are processing, the multiuser capability will allow other instances of the software to access the project. The status description will be updated as the VG4D Production Manager completes the filtering of all tiles. As the filtering is completed, other workstations will be able to access the completed tiles and begin the manual editing process.
- After the tiles are filtered the Attributes Table for the Filter polygon layer (Right Click on the filter polygon layer and select Attributes Table) is updated. Figure represents a filter polygon that was drawn with the graphics tool. Notice the column “Whole Tile” says False. This indicates that the entire tile was not classified, only the area within the Filter polygon



Attributes of FILTERPOLYGONS

Total Number of Records are 4 and Total Number of Attributes are 8

Record Nur	Name	MacroName	MacroFName	TileNames	WholeTile	Status	TileShape	Refference
1	filterpolygor	ground surface	C:\Users\Caltrans\Desktop	C:\Users\Ca	false	0	C:\Users\Ca	
2	filterpolygor	ground surface	C:\Users\Caltrans\Desktop	C:\Users\Ca	false	0	C:\Users\Ca	
3	filterpolygor	ground surface	C:\Users\Caltrans\Desktop	C:\Users\Ca	false	0	C:\Users\Ca	
4	filterpolygor	ground surface	C:\Users\Caltrans\Desktop	C:\Users\Ca	false	0	C:\Users\Ca	

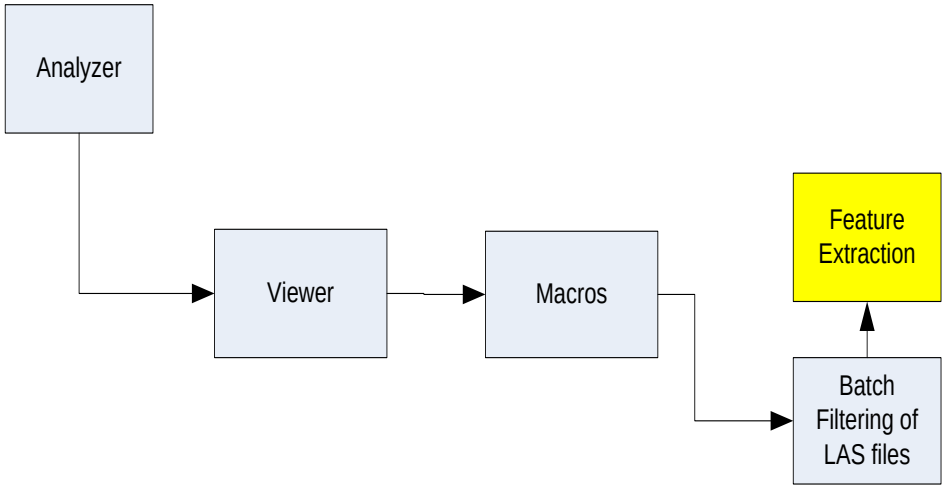
Figure 57: Attributes of Filter Polygons

- The “Status” Column indicates whether the tile was completely filtered. A number 0 indicates the tile completed filtering. If there were a value of -9999 in the “Status” column, the filtering was not completed on this tile.
- If the software is interrupted during filtering, this attribute table will show where the filtering left off. Restarting the filter polygon by going to Ground LiDAR Workflow -> Autodata Classification -> Run Classification Polygons will read this attribute table first, figure out where it stopped and start over from that point.

Reset Filter Polygons

- This function will reset the “Status” column in the filter polygon attribute table and allow the filter polygon to run from the beginning.

Chapter 5: Feature Extraction



In order to understand the process of Feature extraction like Lane Lines, Curb Lines, DTM, and Concrete Barriers we have to get acquainted with the Profile Viewer in LiDAR Viewer.

Profile Viewer

The VG4D 3D Viewer has the capability of viewing point cloud data as a profile. To open data in the Profile Viewer

- Select the **Profile View** button on the VG4D Viewer toolbar
- The cursor will turn into a crosshair; select the starting point of the desired profile with a single left mouse button click
- Move the cursor to the endpoint of the desired profile and single click
- Set the width of the profile with a single click
- The profile view window will open
- To get out of Profile mode Select the Normal Viewing Mode button then close out the profile window by selecting the close button in the upper right corner

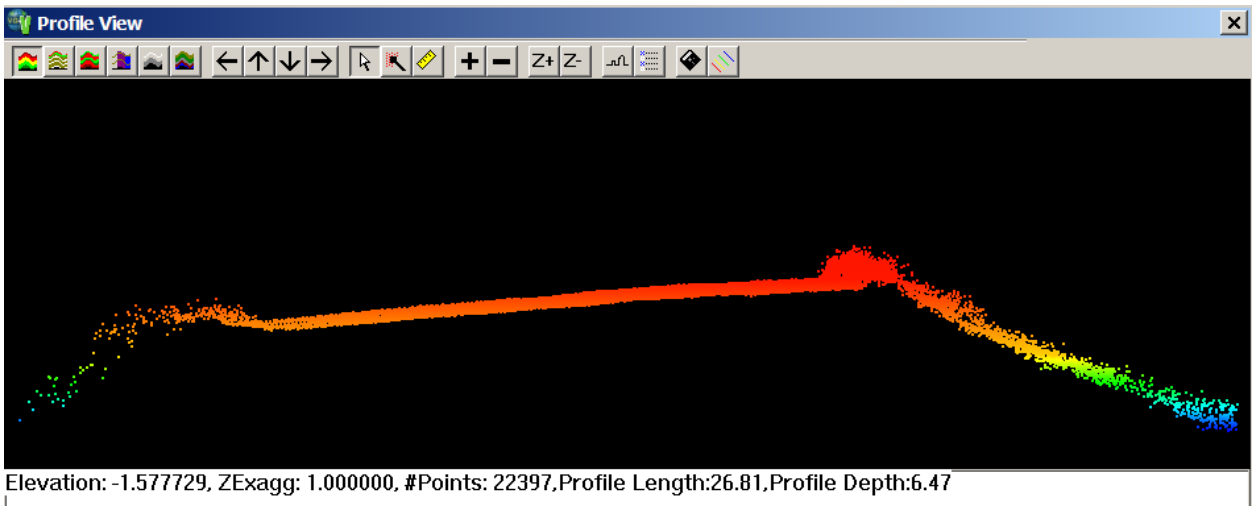


Figure 58: Profile View

- Majority of icons in the profile view are same and have same function as described in the Viewer. Instead of the 3D view the profile view shows the cross sectional view. You would also observe a limit box in the 3D viewer having a rectangle which moves as you move the scene in the profile view which actually shows the active area. One may also use the direction arrow keys for navigation.

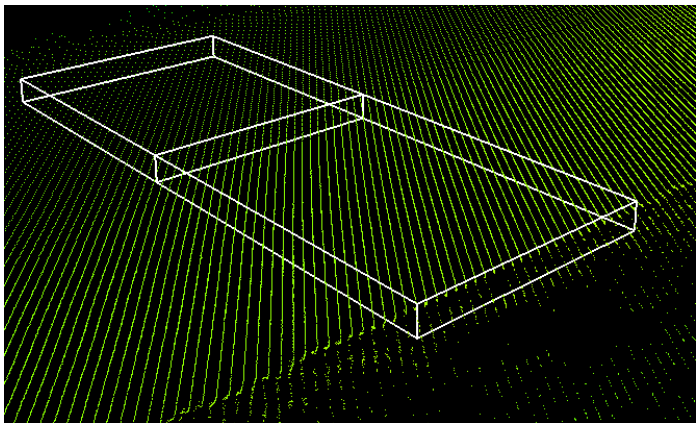


Figure 59: Limit box in 3D Viewer

Point Editing Mode

In the 3D Viewer toolbar select the , then click on the area where editing will be started. The options in dialog box are as explained below:

Table 1: Various Function in Point Editing Mode

Function	Defined	How to use
Output Class	Select the layer to edit points to	Pull down and select the appropriate class
Brush Size	Paint brush size	Select the size of the brush. Move the brush cursor over the points that need to be edited
Class to Protect	Classes can be selected to be masked from the editing	Select the class(s) to be protected from editing. This is expanded option of "What to change" gives more flexibility to user to choose what to mask and what not to
Trimmer	*No Trimming* - This option will classify all the points that fall inside the edit cursor.	Select as needed
	High Point Trimming - This option will automatically classify points with high elevation that falls inside the edit cursor. Very useful to remove vegetation in a hilly and/or highly vegetated area where surface is obscured.	
	Low Point Trimming - This option will automatically classify points with low elevation that falls inside the edit cursor. Very useful to recover surface points in a hilly and/or highly vegetated area where surface is obscured	
Use Mask as Protected Class	Check this to include Mask class(es) in high/low elevation calculation (during high/low trimmer) but not to use them in classification	Select as needed
Undo	Set the number points edited to be undone for each button click	Click **Undo** to undo the last designated number of points edited

Feature Extraction

Feature extraction can be done by two methods: Automatic and Manual Selection of Points in VG4D. Let's take an example of Lane Line Extraction to illustrate the process

Lane Line Extraction

VG4D offers very intuitive tools for feature extraction. We will first extract lane Line using Automatic Process.

Automatic Extraction of Lane Line

- Open the LAS file using Viewer in editing mode
- Run the following filters: All Reclassify Points and Road surface extraction filter using the steps described in previous chapter. You will have the road surface with curb and lane lines to begin with this tool
- Zoom in considerably close to the feature which is lane line. This is solely required in order to snap the points on the lane line thereby avoiding any errors
- Click on Point Editing Mode icon  in the toolbar

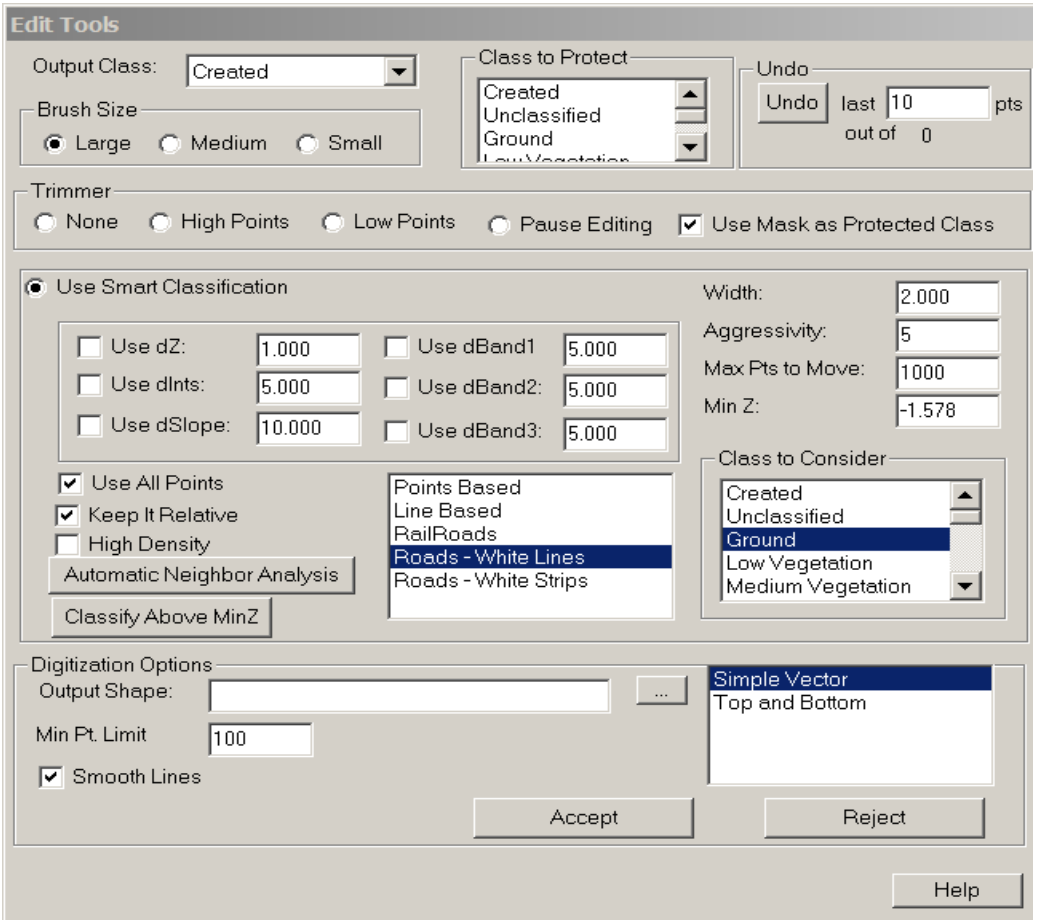


Figure 60: Point Editing Dialog Box

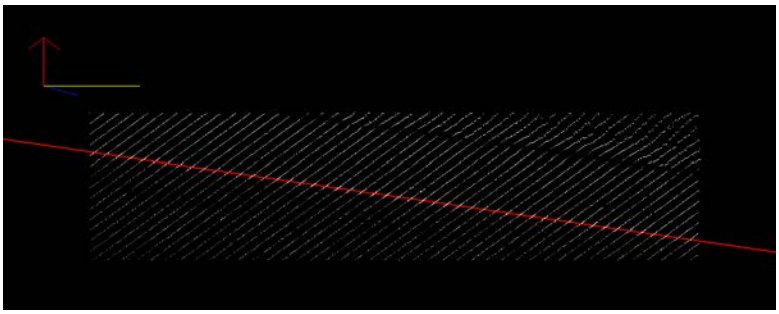


Figure 61: Lane Line Extraction

- Specify the Output class where the lane line is required to be moved to. This can be further exported as a shape file or a pts/LAS file if required
- Select Smart Classification and Specify the width (normal values range between 0.1 to 2 depending upon the accuracy required)
- Select the Method of extracting the line. In this case we want to extract the Road- White Lines (Lane Lines). Hence select Roads- White Lines
- Since we classified the Road surface to Ground Class, Select Ground Class in *Class to Consider*
- Select Simple Vector in *Digitization Options*. Use the options of *Top and Bottom* when curb line is to be extracted
- Using left click, specify the first point on the Lane line followed by second point. The line would automatically track along the entire lane line which can be observed by zoom out
- Click on Accept to accept the command
- On Zoom out, you can observe the lane line extended along the entire strip.

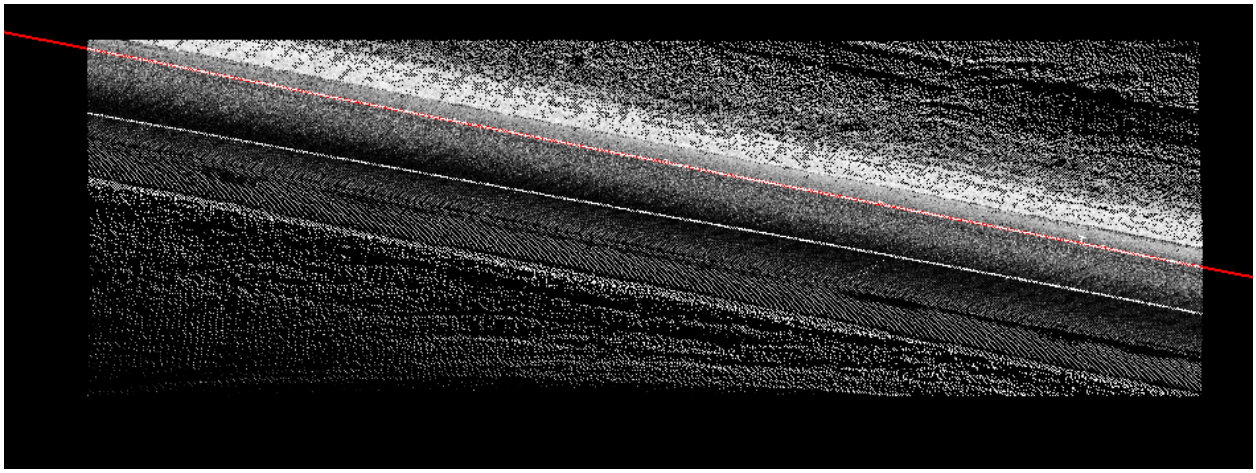


Figure 62: Automatic Line Extrapolation of Lane Line

Manual Classification of Points

- Select Point selection command
- Follow the previous steps as described above except selecting Trimmer instead of Use Smart Classification
- Select '*None*' option in Trimmer. A square shape cursor would appear in the viewer which would be used for picking up the points
- Specify the class where the desired points are required to be moved to

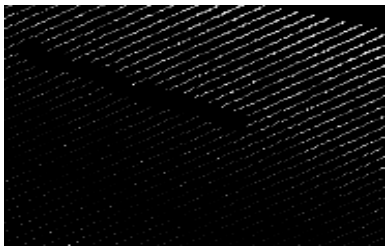


Figure 63: Black Strip Area in the figure shows the manually selected points

Editing in the Profile viewer

- Select the section of the road strip where manual classification of points is required. A limit box would be drawn in the selected area in the Viewer and a separate Profile view window would be visible
- In the Profile Viewer, click the Edit Button  . This will bring up the Profile Viewer editing tools window
- Draw the shape as per the requirement of the points to be classified

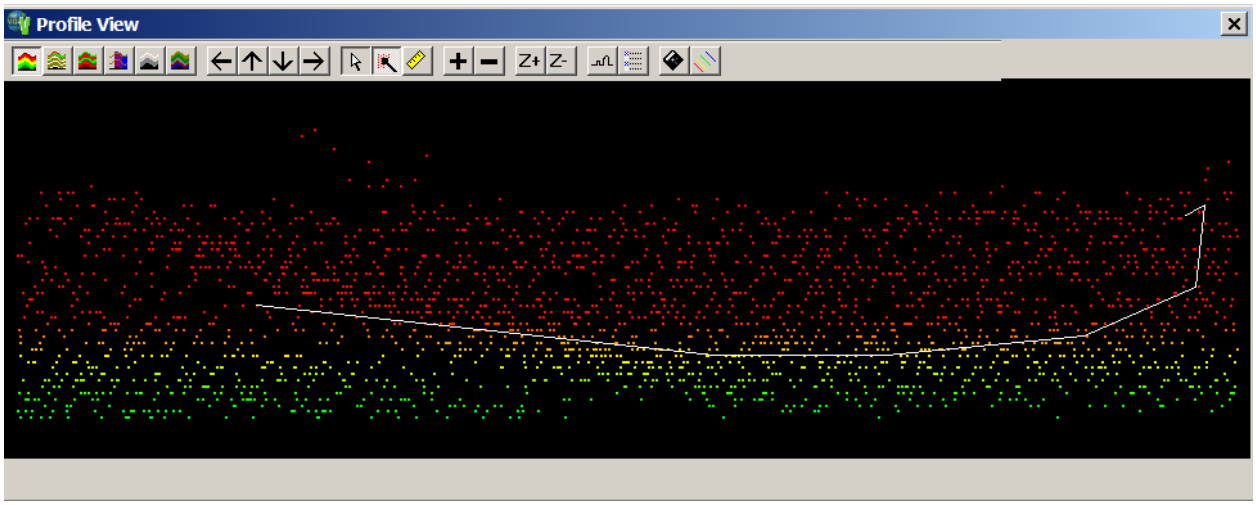


Figure 64: Manual Selection of points using Line Method in Profile View

- A dialog box (as seen in figure 65) shows the Edit Mode and output class. Select line based edit. Assuming we would require the points above the white line select the option

Above Line and specify the name of output class (figure on the next page). You may also pan along the points using the interactive arrow buttons.

NOTE: *This option would be widely used for selecting concrete barriers, guard rail, sign posts and other attributes which do not have any intensity or RGB value for automatic selection. Since it is not an automatic process, the user has to manually move the limit box along the entire strip for manual selection of points.*

- Undo options can be used if reselection is required

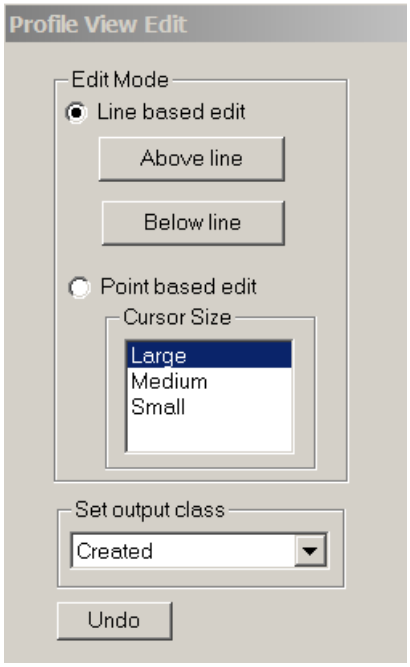


Figure 65: Profile View Edit Dialog Box

- The Point Based option works like the Main View Editing. Select a class, cursor size and Hold the left Mouse button and move the cursor over the points that needed to be edited. Set the Output class as desired class where the points will be moved.

Case Study: Extraction of Concrete Barriers

- Open an LAS file having a concrete barrier
- Click on Profile viewer icon to open the profile view

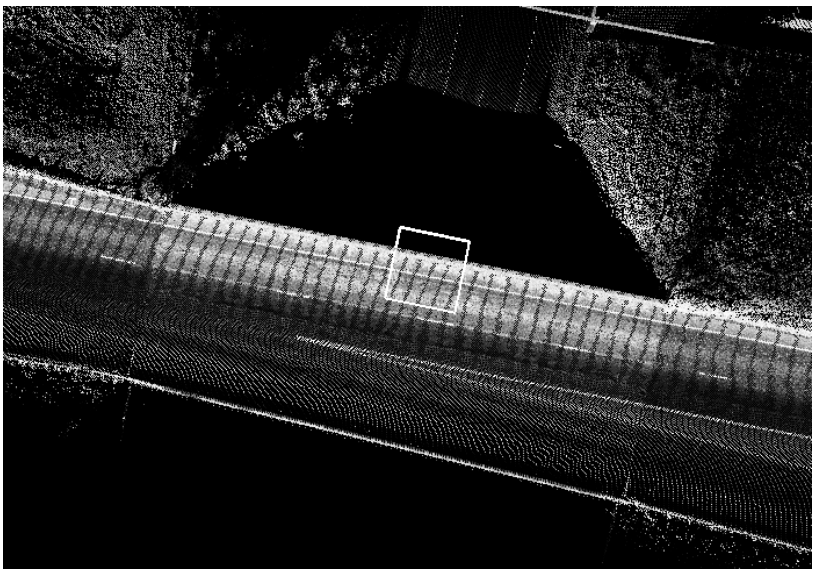


Figure 66: Limit Box Showing Concrete Barriers

- You may ensure the limit box is perpendicular to the barrier using On-the-Fly Settings icon 
- Use the interactive arrow icons to achieve the desired size of the limit box

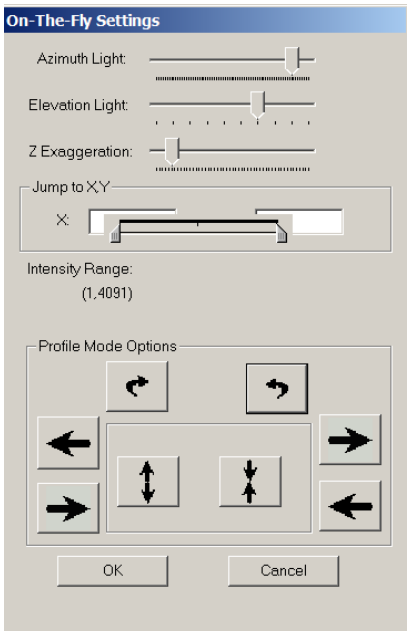


Figure 67: On-the-fly settings

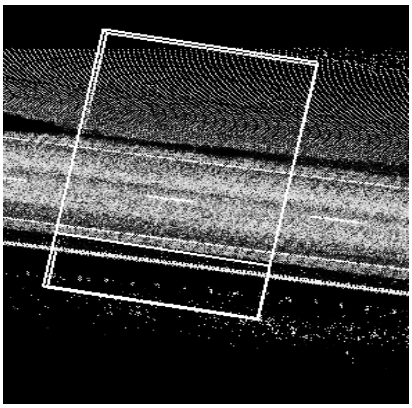


Figure 68: Limit box for concrete barrier

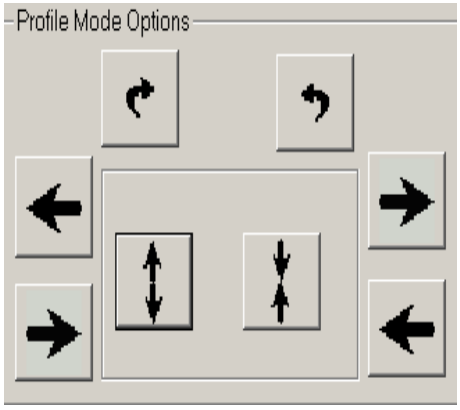


Figure 69: Arrow keys for aligning and resizing

- Once the limit box is adjusted, switch to profile view window and click on Point Editing Mode icon 
- There are two methods for selecting points: Point based edit and Line based edit
- Specify the output class where the selected points will be saved/moved to

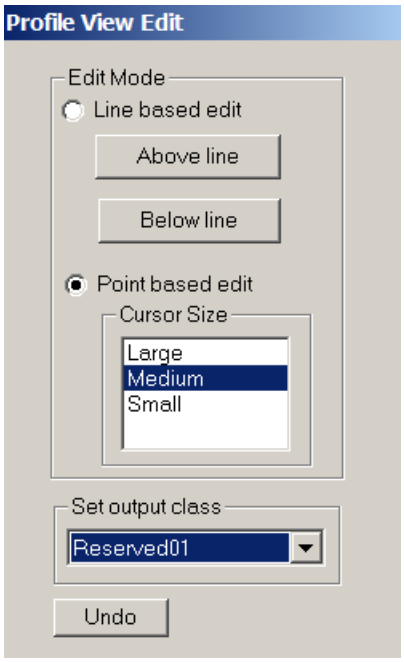


Figure 70: Manually Selecting the Points of Concrete barrier

- Point based edit can be used for selecting particular points or when the selection of points is very local in the entire LAS file. Figure below shows the points being selected and moved to the class Reserved 01. The cursor size can be changed from Small to Large depending upon the requirements.

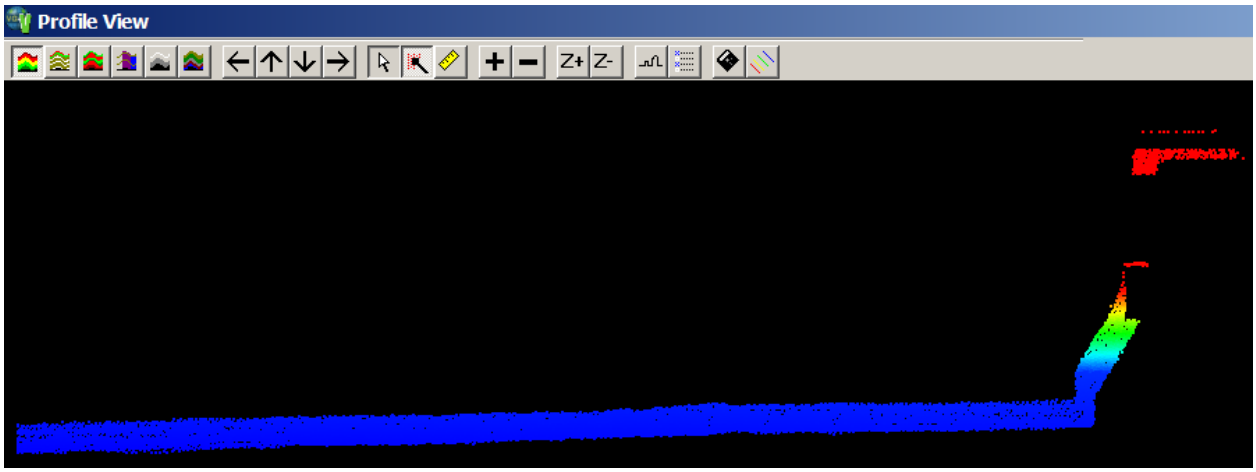


Figure 71: Manual selection of points

- One may also use line method for selection of points as shown below. You need to draw a line by left clicking on the points in the profile view and double left click once the selection is done.

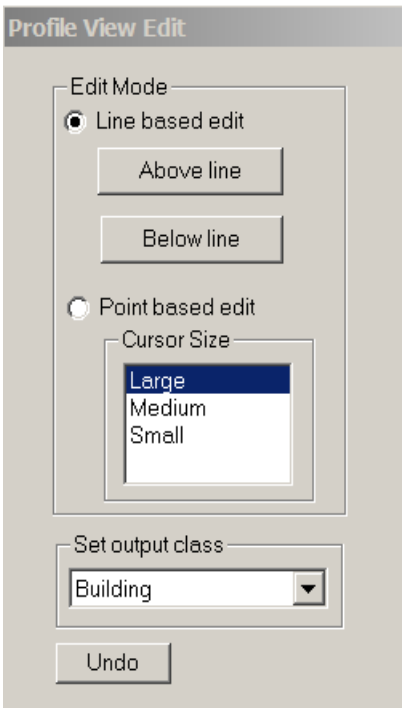


Figure 72: Profile View Editing

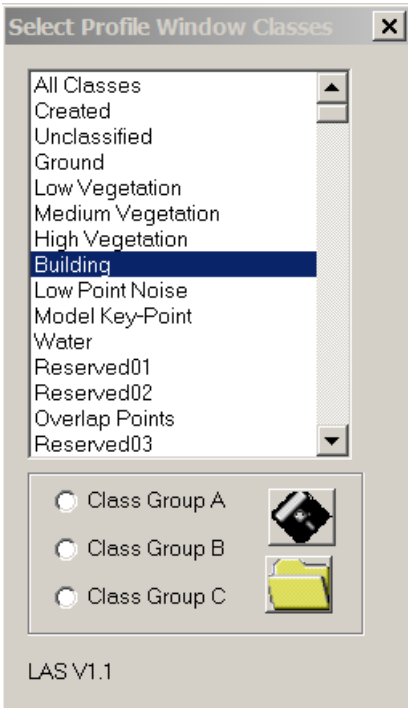


Figure 73: Classification Selection Tool

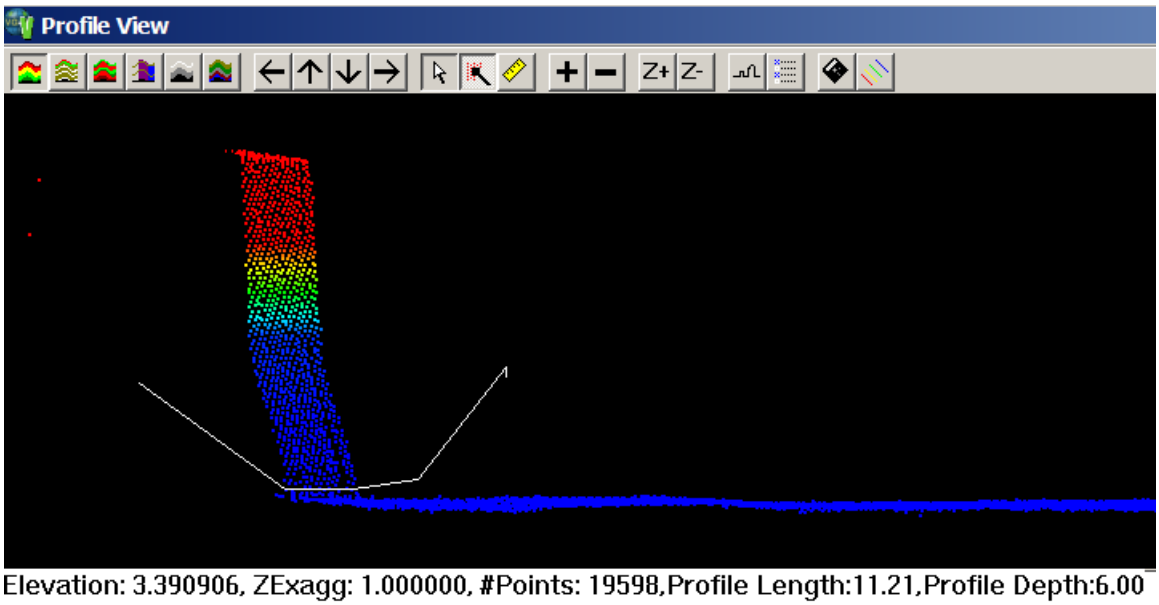


Figure 74: Feature selection using Line method

- Since the selected points are moved to the new class, they can be viewed by clicking on the  icon in Profile View as well as LiDAR Viewer to view in 2D and 3D respectively

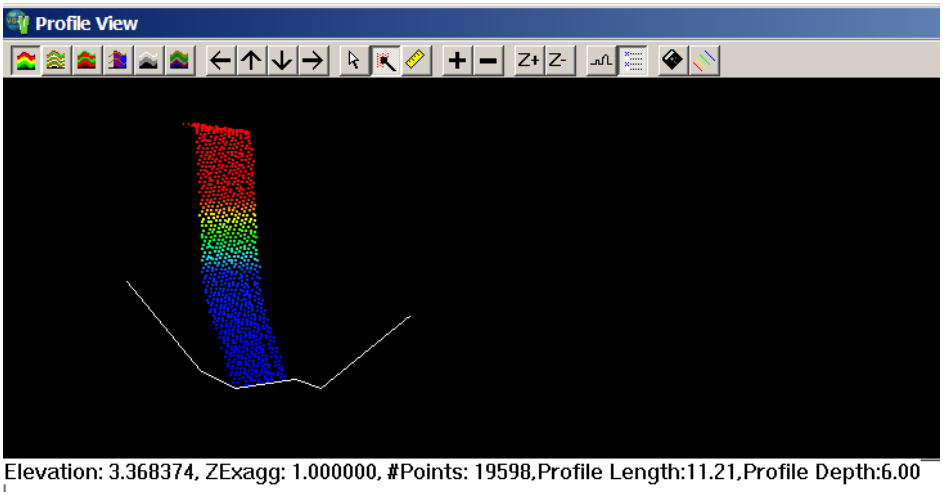


Figure 75: Selected points in separate class

- Also it is required to select all the points along the barrier by using the arrow keys to move the limit box and repeating the above procedure (by either point or line method)

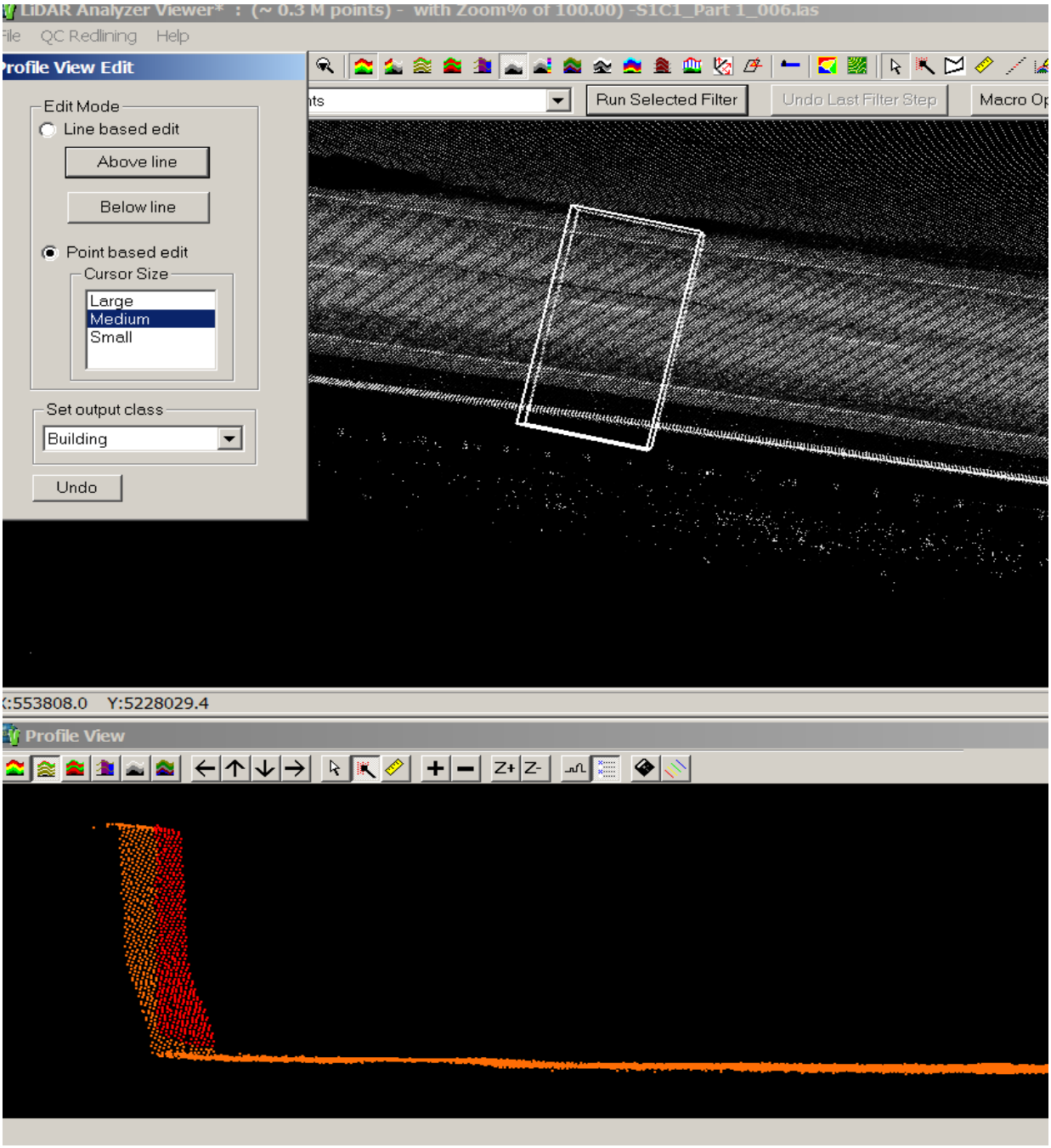


Figure 76: Selecting the points by moving the limit box

- Alternately, the limit box can be increased in size such that the points are classified in single process as shown below.

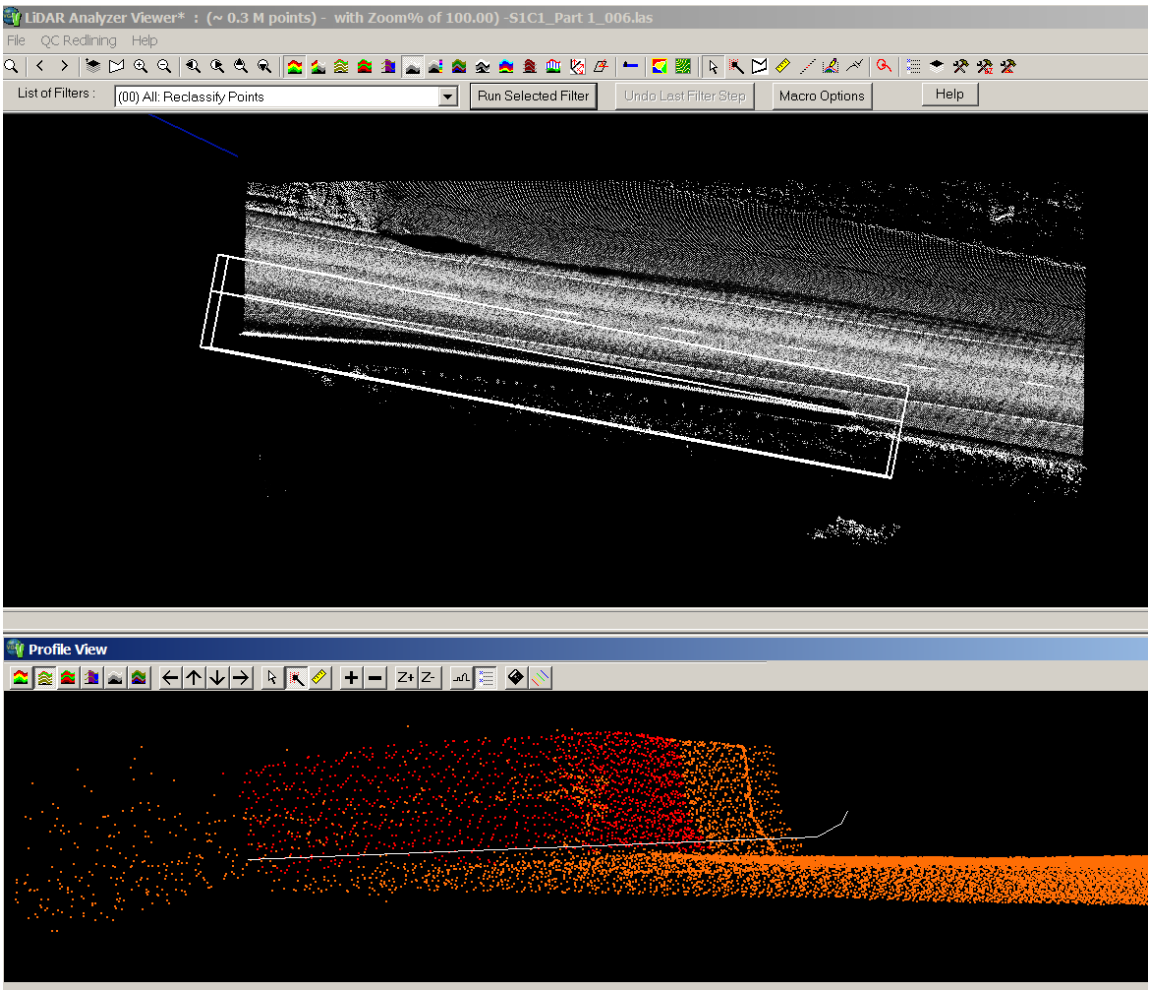


Figure 77: Classifying all the points together

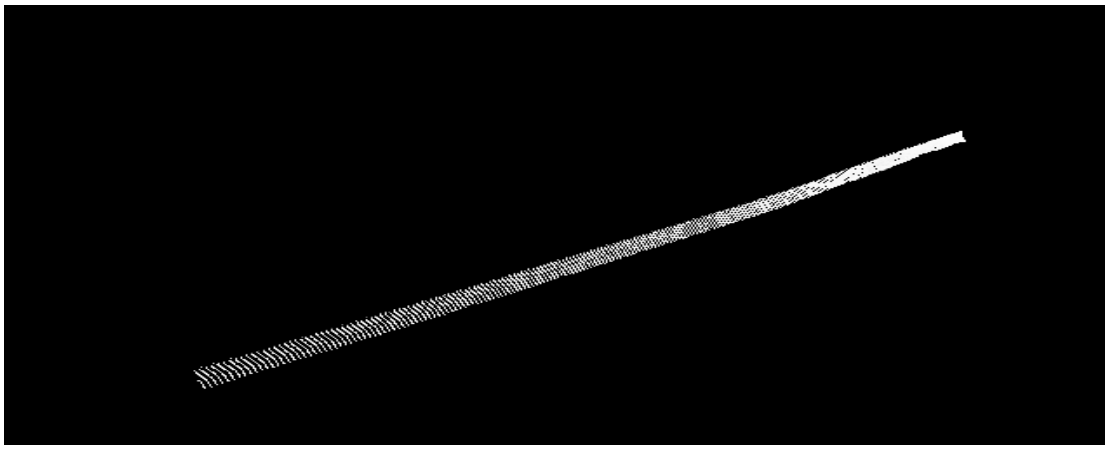
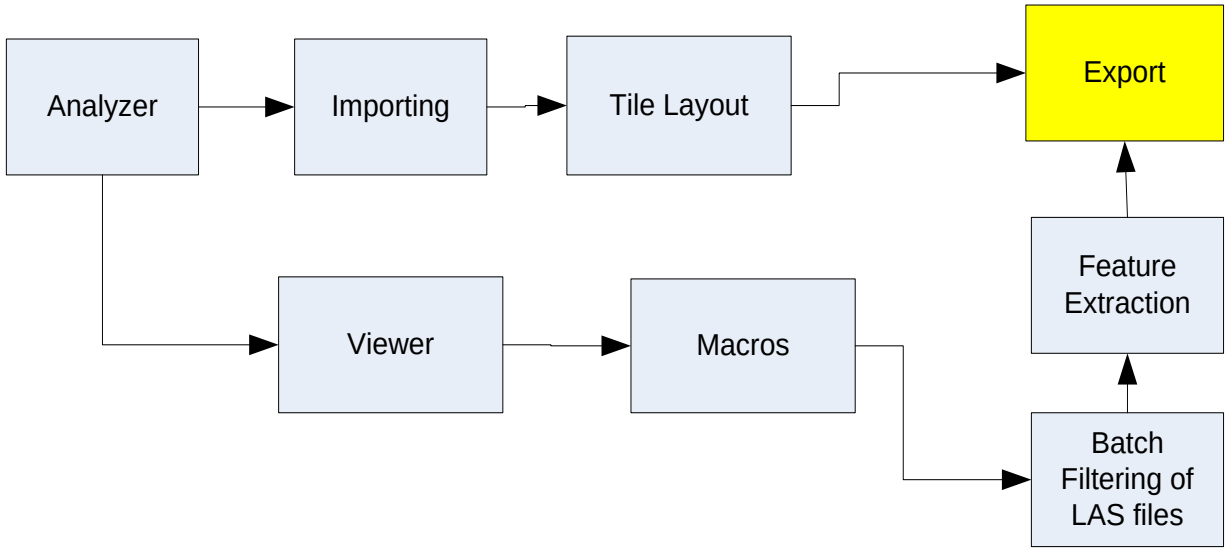


Figure 78: Classified points for concrete barrier as seen in LiDAR Viewer of VG4D

CHAPTER 6: Exporting Data, Report Generation and Data QA/QC



There are various methods of exporting the data from VG4D:

Vector Conversion by Tile/File

- Switch to VG4D Analyzer. Select Ground LiDAR Workflow -> Create Deliverables -> Point Export by Tile/File

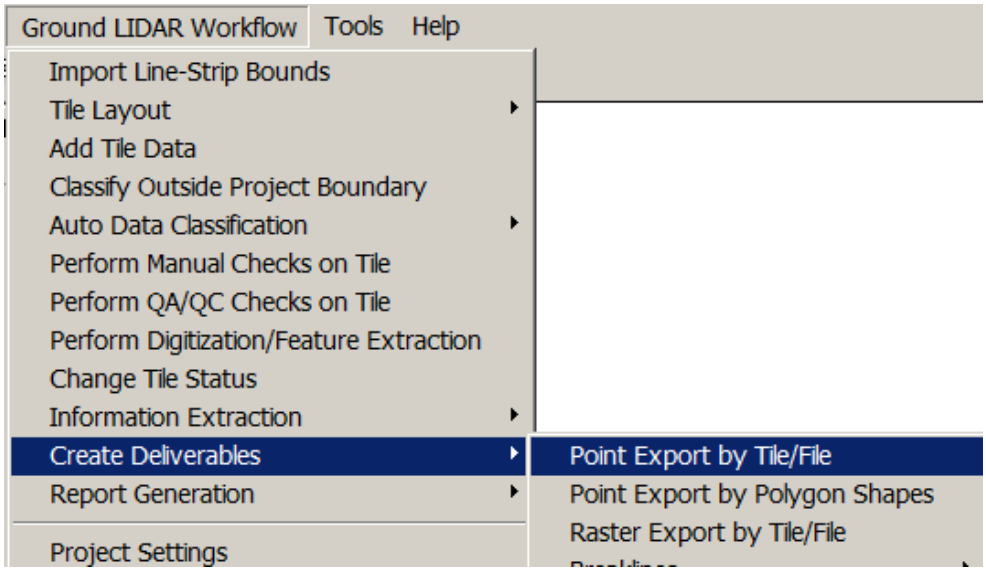


Figure 79: Point Export by Tile

- A dialog box (Vector Conversion by File) opens as shown in Figure 80

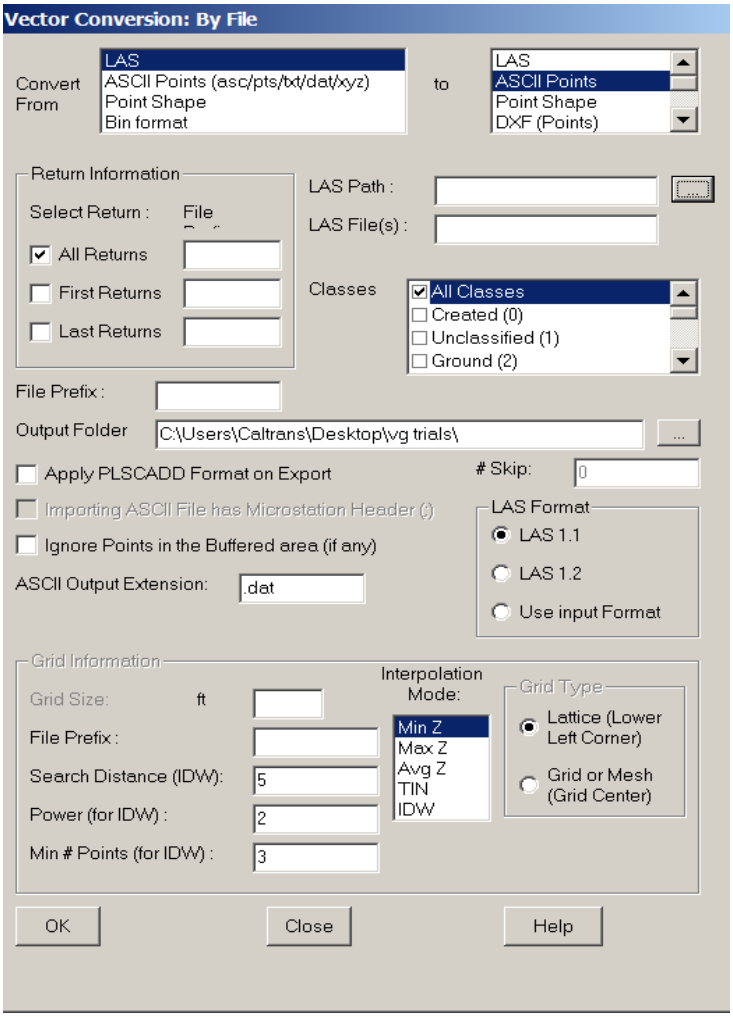


Figure 80: Product conversion pull down menu

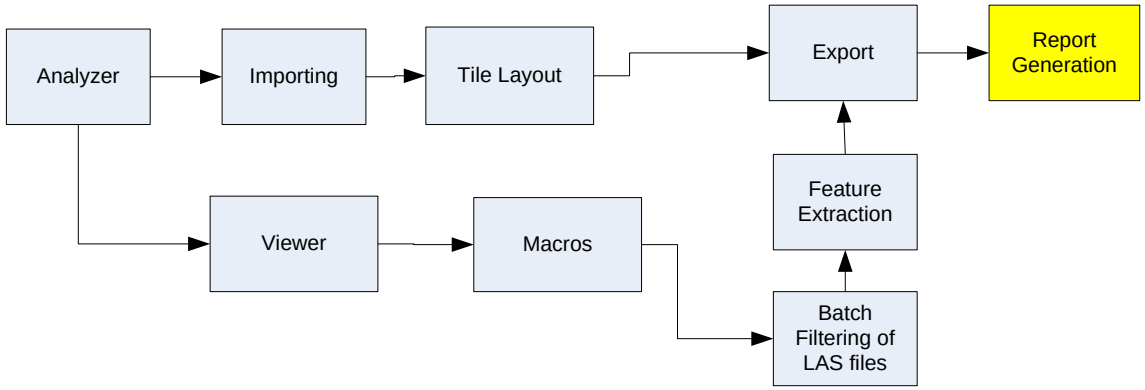
- The options explained in the conversion dialog box are are follows:

Table 2: Options in Product Conversion Pull-down menu

Input	Defined	How to use
Convert From	Default if LAS because VG4D works directly with the LAS format.	Leave Default
To	Output format both point and grid formats available.	Select the required output format. Multiple formats can be selected and created at the same time.
Return Information	All Returns, First Returns and/or Last Returns can be specified for output.	Select which set of return are required for output.
Classes	List of Classes that can be selected for output.	Select the necessary classes for output. If output is to be Bare Earth, select the ground class only.
Create Metadata	Two different file formats available: XML or ASCII	Select metadata format if required.
File Prefix	A file prefix can be added to the output files.	Select the relevant prefix as needed.
Output Folder	Where the output files will reside.	Select an appropriate file location for the output. Make sure there is ample space.
Ignore Points in the Buffered Area	If Tiles were created with buffers, this option will remove those access points.	Select as required
LAS Format	Two LAS output formats are available: LAS 1.1 and LAS 1.2	Select the required LAS format.
Grid Size	If exporting an LAS or ASCII Grid, input a grid size.	Input the specified grid size.
Grid Type	If exporting a grid select the appropriate way to define the grid for the application using the data.	Select either Lattice (Lower Left) or Grid/Mesh (Grid Center).

NOTE: It is also possible to export the output data by a different tile scheme using Vector Conversion by Polygon. For details please refer to the manual.

Report Generation



Log Report Generator

- This command generates a report in the form of a text file that logs every event that occurs from start to finish in the project production lifecycle. This report is saved as .txt file in the project folder. Switch Window to LiDAR Analyzer.
- Select Ground LiDAR Workflow -> Report Generation -> LOG Report Generator

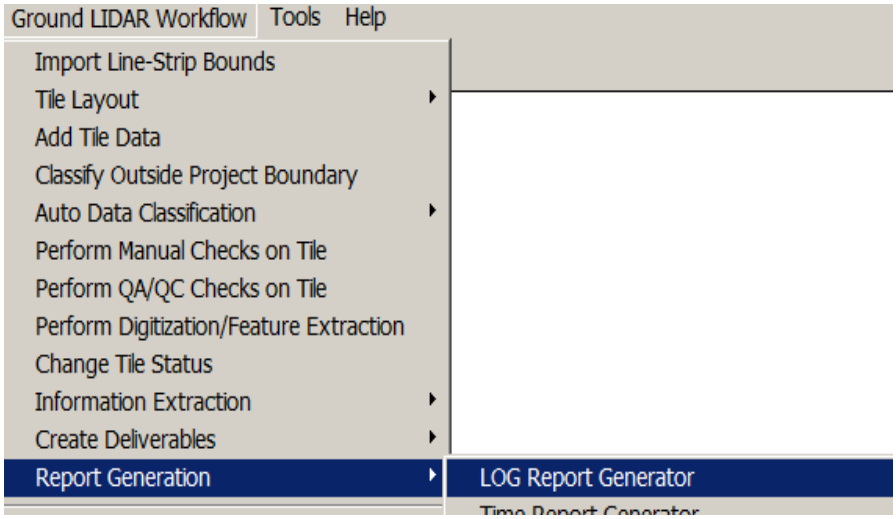


Figure 81: LOG Report Generator Command

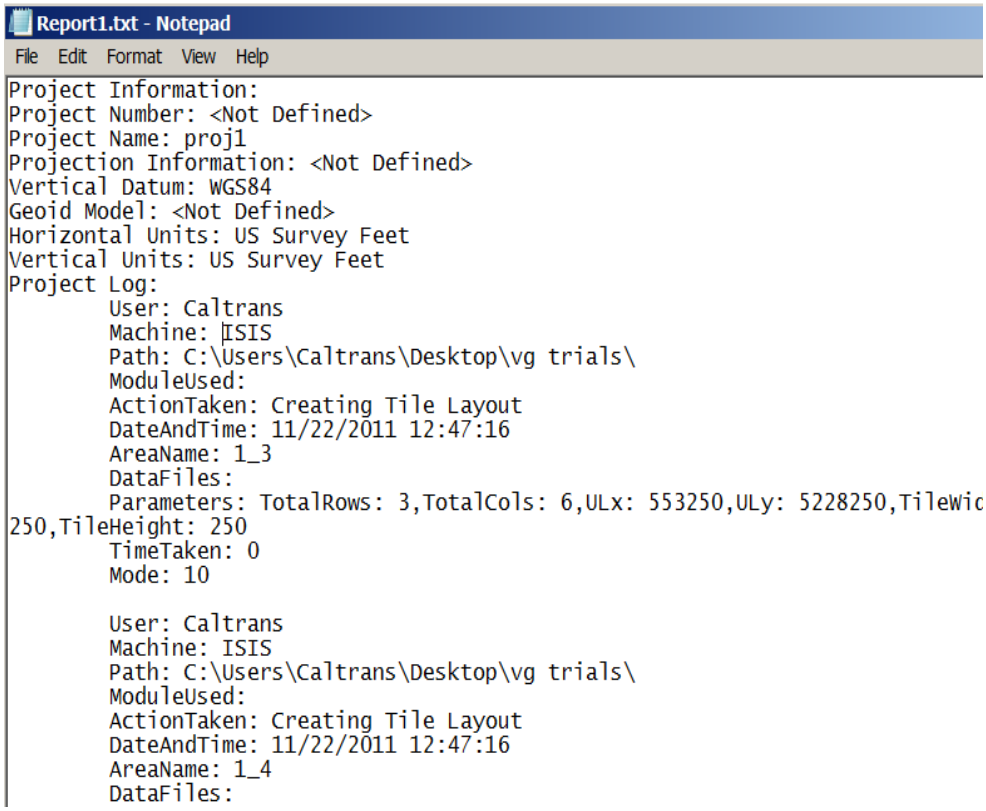
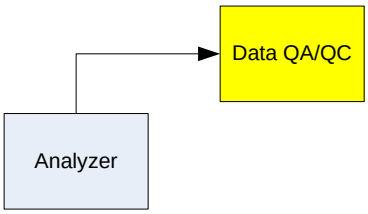


Figure 82: A sample report

Time Report Generator

Similar to the Log Report, this reporting method has an emphasis on time. The user can select the user names, tiles and customize the report as per the requirement.

Control Point Quality Report Generator



This report is designed to compare the accuracy of the LAS data to a high accuracy ground control point file. Click on Ground LiDAR Workflow -> Report Generation -> Quality Report Generation

- Specify the path of LAS files for which QC is required to be done

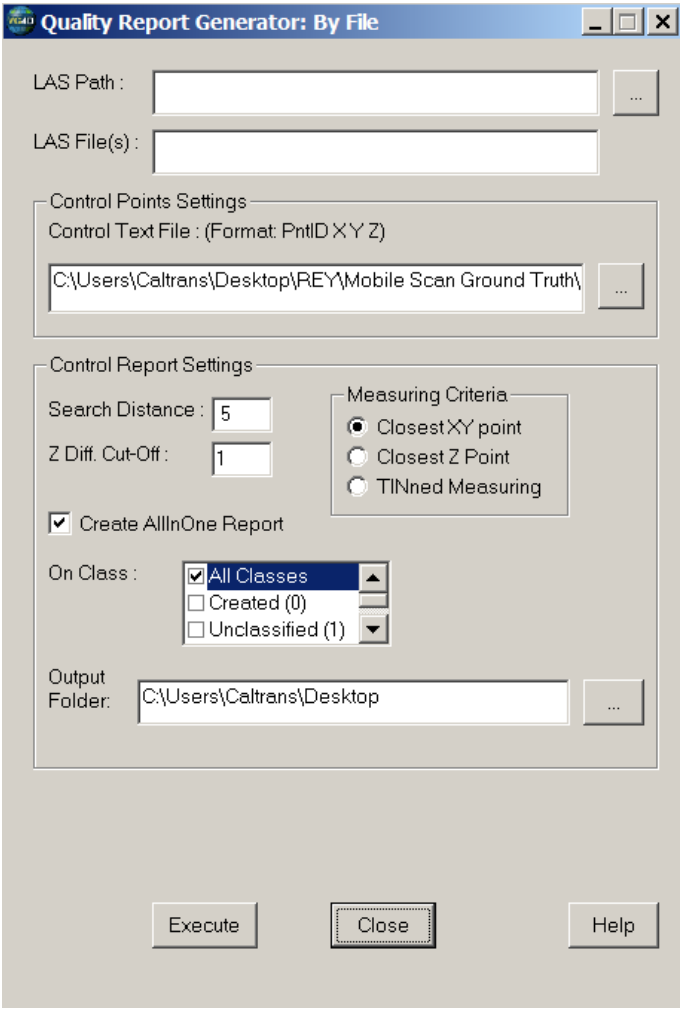
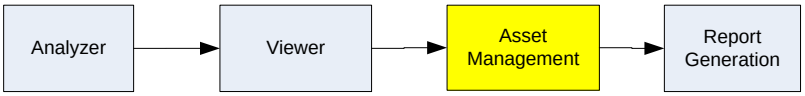


Figure 83: Quality Report Generation by file

- In Control Point Settings, specify the path of Control Points file which would be a text file.

- Search Distance is the distance threshold that the report generator will use from the ground control point to find a LiDAR point to compare. Select a search distance that will do the best job of finding a point close to the control point.
- Z Diff. Cut-Off Eliminates the opportunity of the report generator using an outlier point in its generation of statistics. Select cut off that will eliminate the chance of outlier being used in generating statistics.
- Select the classes that will be used in the classification.
- Specify the path of output folder where the generated text file report will be created.

Chapter 6: Asset Management



Asset Management

- The very first step is to import a strip i.e. a LAS file in Analyzer and create tiles as explained in previous chapters
- Click on Ground LiDAR Workflow - > Perform Digitization/Feature Extraction

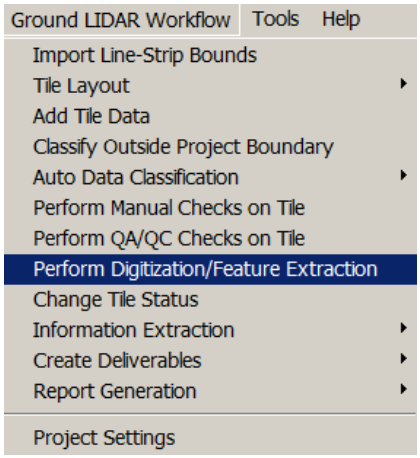


Figure 84: Asset Management Command in Analyzer

- A dialog box appears as shown in figure 85
- Click on Image folder and browse the path of folder containing all the image files
- Specify GPS offset and buffer distance if any
- Click on Add files and specify the path of corresponding LAS files
- The imported files would be visible in the dialog box as seen in figure 86
- Click on Ok

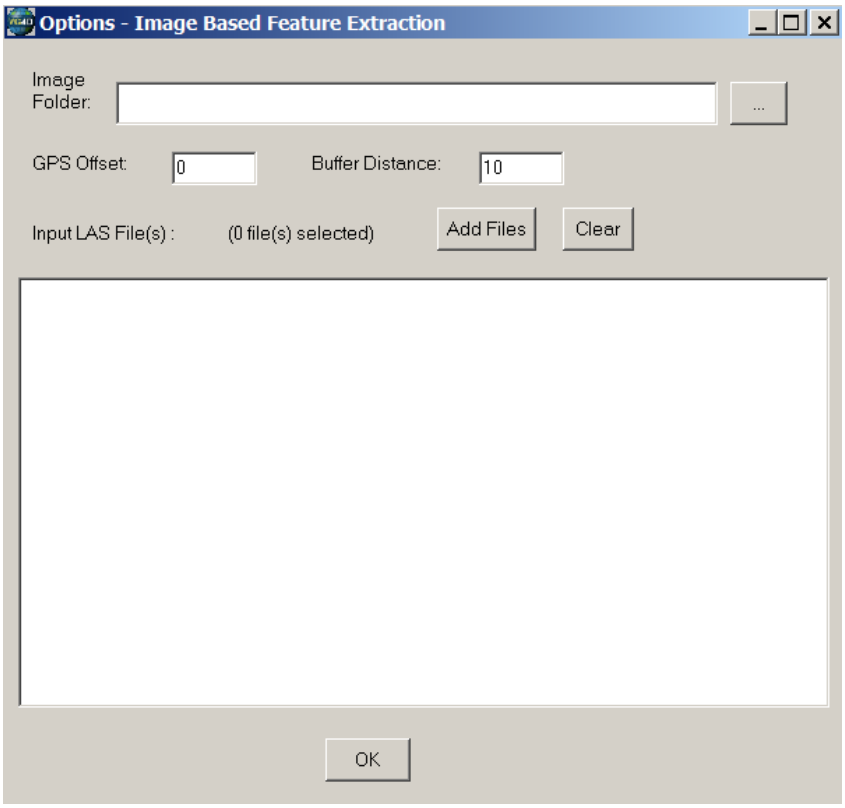


Figure 85: Image Base Feature Extraction

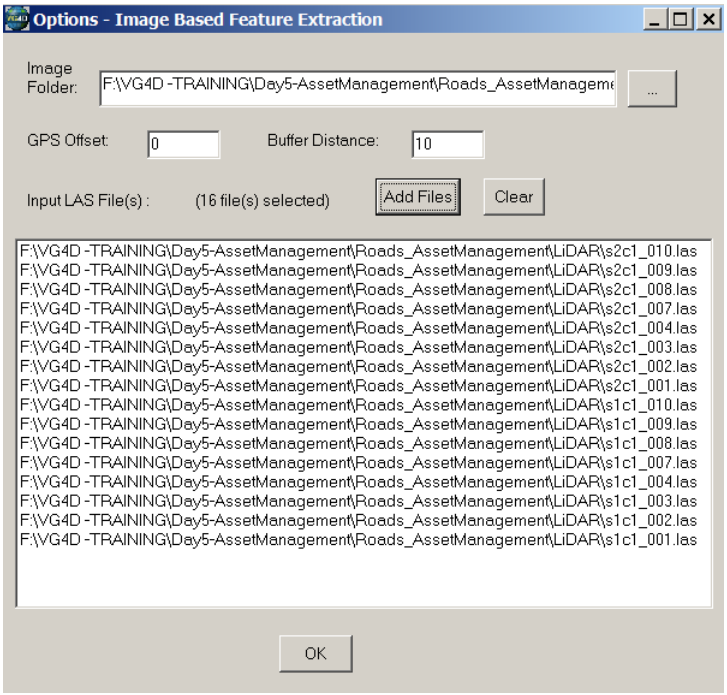


Figure 86: Data imported for Image Based Feature Extraction

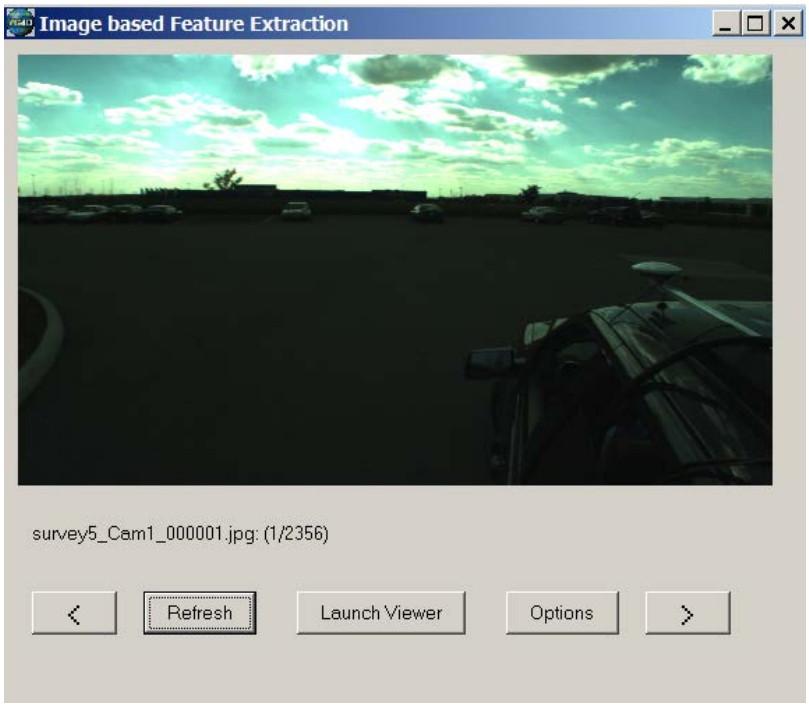


Figure 87: Imported Image for Feature Extraction

- A dialog box (Figure 87) opens showing the current image with its image ID and total number of images in entire folder

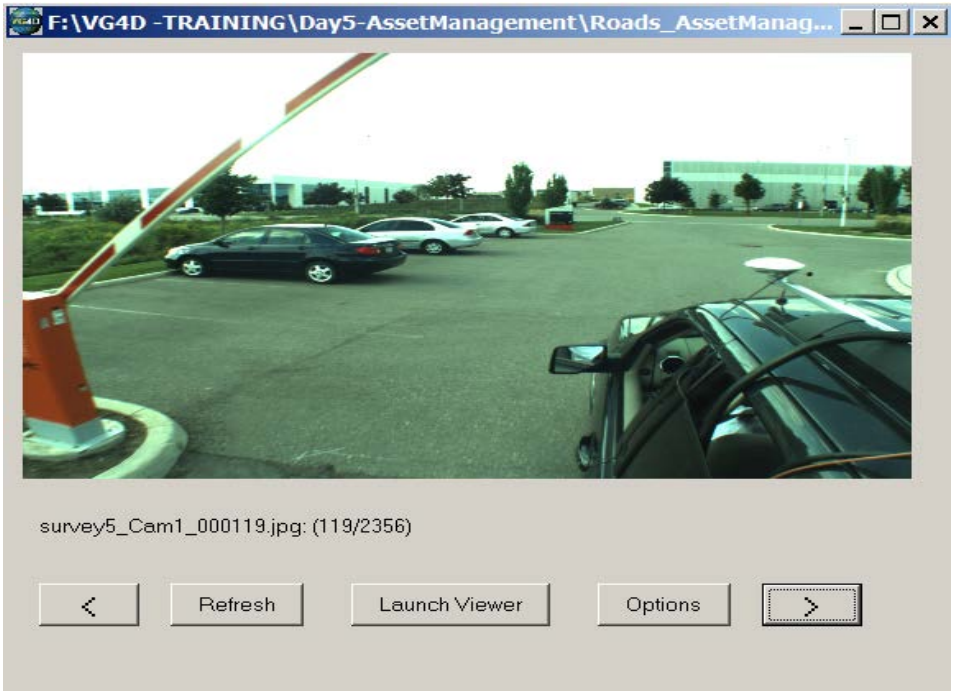


Figure 88: Image viewer for Asset Management

- We may use interactive forward and backward keys to switch images as seen in above figure
- One may even click on the number (in this case it is 119/2536) and go to a desired image location or image ID.
- Click on Launch Viewer to see exactly the same part of image in point cloud format (LAS file)
- Use Normalize Z to Mask Noise option from File -> Preferences for a better view of the points.

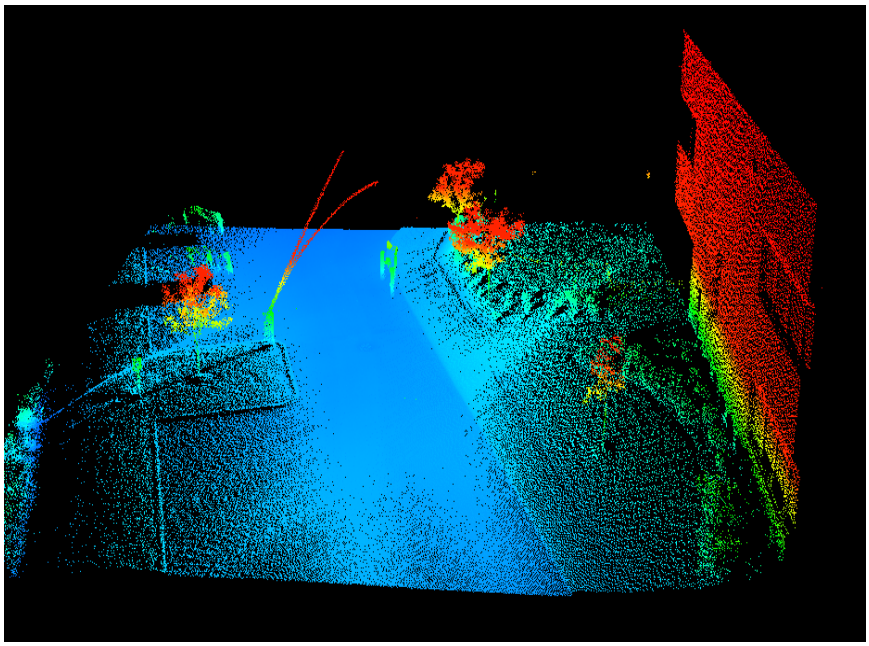


Figure 89: LAS file of the same image

NOTE: The Asset Management links the image files and the LAS files such that the area near the asset can be seen along with the asset feature in point cloud format. However one may also put a Redline comment to mark the name of asset in the Viewer and save it as a shape file.

Asset Management in Viewer

- Asset Management can also be invoked in the Viewer by selecting File -> Show Asset Management Window

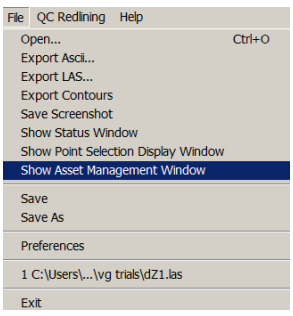


Figure 90: Asset Management using LiDAR Viewer

- A dialog box opens showing Asset Management Extraction
- Specify GPS Offset if any
- Browse the image directory selecting any of the images in the folder
- Browse the path of Survey Index File (this file is always required for asset management which would be generated while scanning the data)
- Specify the path of Output file which would be a shape file. Entries made in the dialog box would be saved as shape file
- The image would be imported as seen in the figure. Click on Next image or previous images depending upon your requirement
- Click on Launch image to open it in windows image viewer

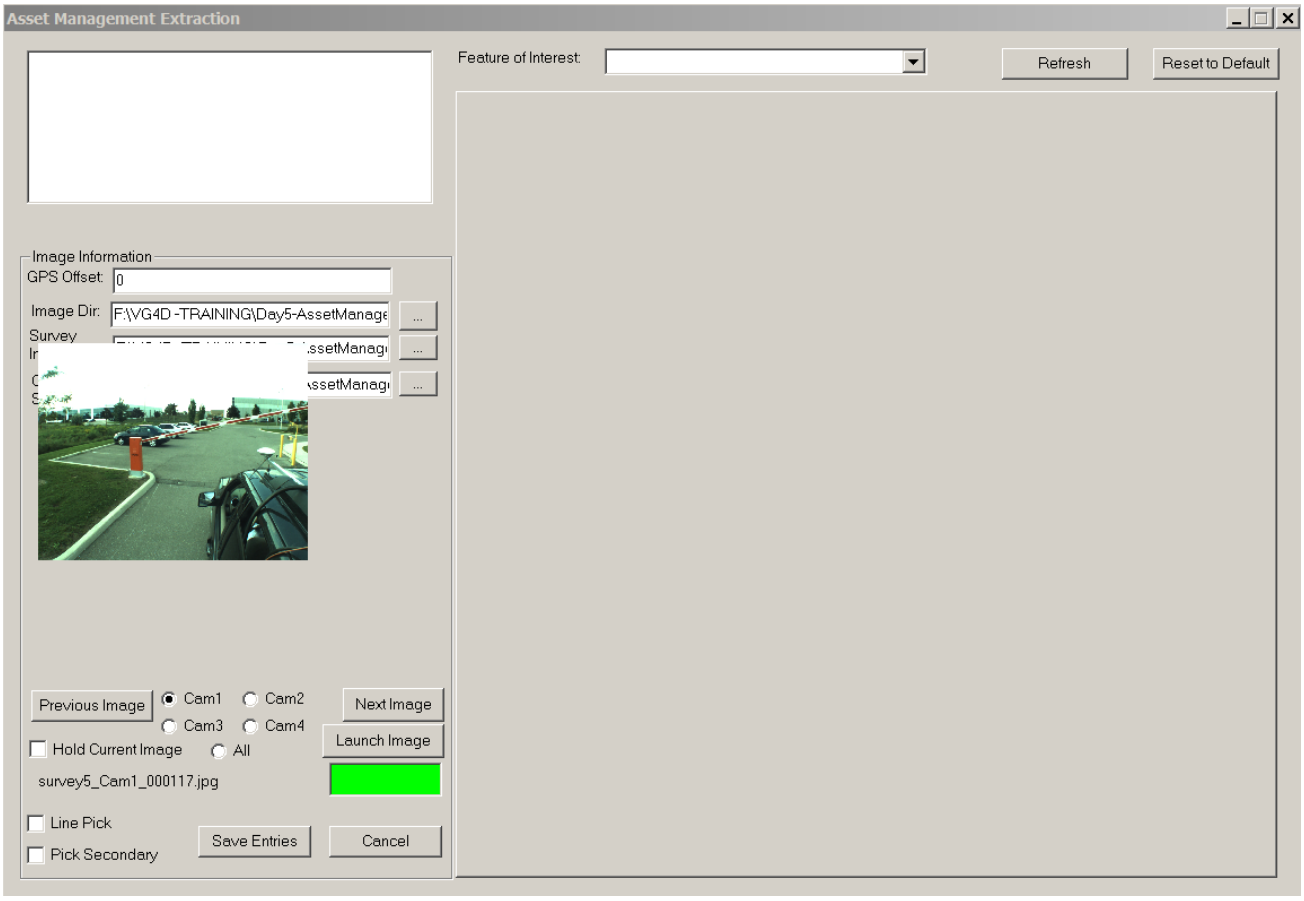


Figure 91: Asset Management Extraction using LiDAR Viewer

Bridge Clearance Measurement

- One may even use the measure tool  in the Viewer for the same purpose but it does not give other details about the bridge clearance
- Double Click the Left button to mark the two points (top and bottom) of the bridge
- Click on Asset Management Extraction and select DOT- Bridges from the Feature of Interest drop box
- The Bridge elevation including Latitude, Longitude, and Height would be automatically measured and displayed if the data in LAS file and survey index file is correct. You may also put other details like Bridge Type, and Bridge Name

NOTE: The Abbreviations at bottom of window in viewer are seen as

X:618319.607 Y:4849464.087 Z:162.178 Ground Rn: 1 I:20 F: 0 A:-89 Ht: 0.001

where X, Y, Z are the coordinates of the Point. Rn is Return value of the pulse which mostly has a value of 1 unless a point is on the vegetation where we have multiple returns. I is for the intensity, F stands for file ID, Ht for height. One would also observe RGB value if the data is recorded in the RGB form and one may use LSF filter for classifying the data as per the RGB

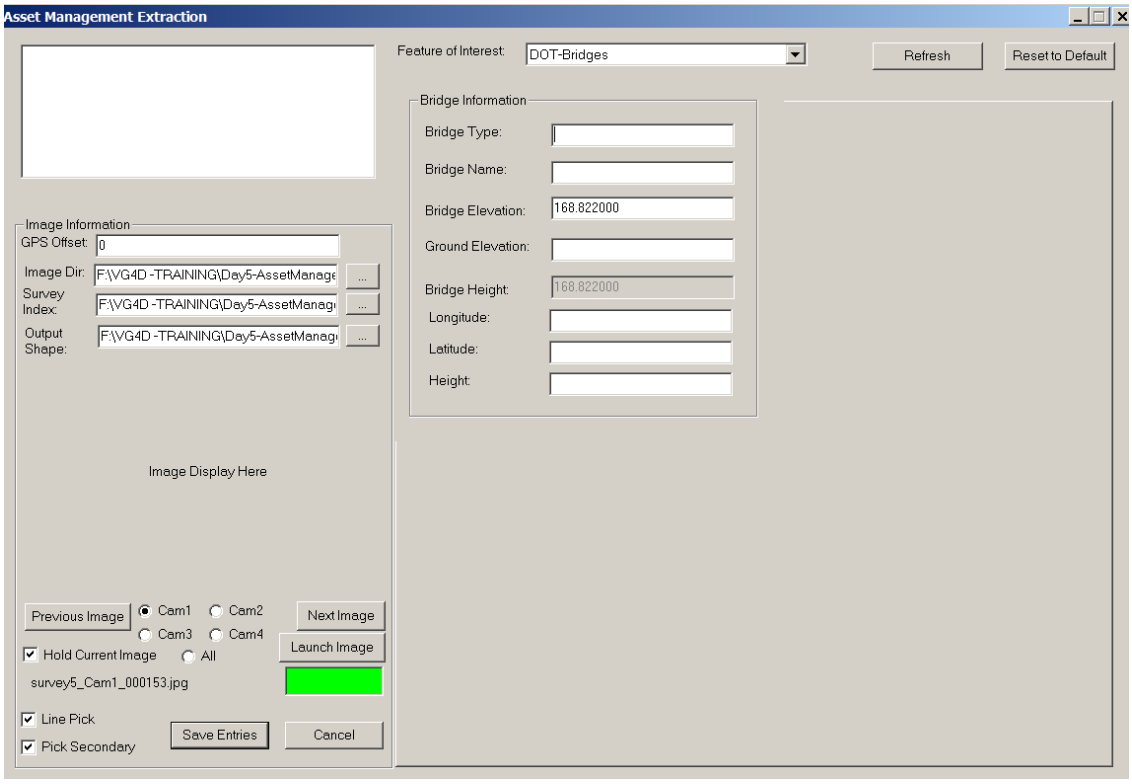


Figure 92: Bridge Clearance measured using Asset Management Toolbox

Table 3: Some of the Shortcut Keys in Viewer

Hot Key	Description
F1	Help
Right Arrow	Rotate view clockwise
Right Arrow + Shift	Pan East
Left Arrow	Rotate view counterclockwise
Left Arrow + Shift	Pan West
Up Arrow	Rotates View Down
Up Arrow + Shift	Pan North
Down Arrow	Rotates View Up
Down Arrow + Shift	
Shift and -	Zooms out
Shift and +	Zooms in
V	Increases vertical exaggeration
Shift + V	Decreases Vertical exaggeration
Z	Zoom In
Shift + Z	Zoom Out
R (or) Shift + R	Pans view left (in screen) to make room in right
U (or) Shift + U	Pans view down (in screen) to make room in top
L (or) Shift + L	Pans view right (in screen) to make room in left
D (or) Shift + D	Pans view top (in screen) to make room in down
E	Increase elevation angle lighting (ranges from 0 to 90 degrees) in TIN mode
Shift + E	Decrease elevation angle lighting (ranges from 0 to 90 degrees) in TIN mode
A	Increase azimuth angle lighting (ranges from 0 to 360 degrees) in TIN mode
Shift + A	Decrease azimuth angle lighting (ranges from 0 to 360 degrees) in TIN mode
Normal mouse movement	Shows point information in status bar
Right mouse button + mouse move	Distance measure tool, displays the distance in status bar as the cursor pans
Both buttons down	Zooms the View in and out
Mouse Wheel	Zoom Data in and out

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